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COMPUTER PROGRAM FOR PREDICTION
OF AXIAL FLOW TURBINE PERFORMANCE

by

Ennio Macchi

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral R. W. McNitt
Superintendent

R. F. Rinehart
Academic Dean

ABSTRACT:

The report presents a computer program for prediction of performance of single-stage axial turbines of given geometry. The three-dimensional method developed by Vavra is applied, taking account of streamline curvatures and slopes, as well as enthalpy and entropy gradients in the solutions of the equation of motion, and of boundary layer thicknesses in the continuity equation.

A choice among five different loss correlation methods and two flow angles correlations is offered. Loss coefficients and flow angles are automatically calculated from blading geometry and actual flow conditions for every streamline, according to the selected correlation method.

A fair agreement of predictions with several actual turbines experimental results was found in ref. [4], where also the applicability of different available correlations is discussed.

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SYMBOLS

A	Area (in^2)
A_{CL}	Tip clearance area (in^2)
a	Throat opening of blade channel (in)
$\bar{a}$	Non-dimensional throat opening, a/a_m
C	Blade chord, see Fig. 6 (in)
$c\ell$	Rotor tip clearance (in)
c_p	Specific heat at constant pressure ($BTU/lb_m\text{-}^oR$)
dA_n	Infinitesimal area, perpendicular to the flow (in^2)
E	Blade radius of curvature, see Fig. 6 (in)
$\vec{f}_f$	Frictional force per unit mass (lb/slug)
H	Total enthalpy (BTU/lb_m)
H	Boundary layer form factor
K	Boundary layer energy factor
K_{CL}	Coefficient, see eq. (31)
k	Curvature coefficient, see eq. (16)
$\vec{i}$	Unit vector
i	Incidence angle
L	Mean distance between the stations 0 and 1 and 1 and 2 (in)
M	Mach number
m	Boundary layer exponent
$\dot{m}$	Mass flow rate (slug/sec)
$\dot{m}_{CL}$	Mass flow rate passing thru the rotor tip clearance (slug/sec)
NSETS	Number of conditions for which performance values have to be found
O	Blade opening (in)
P_T	Total pressure (psi)
p	Static pressure (psi)
q	Heat exchanged with external sources per unit mass (BTU/lb)
R_G	Gas constant ($ft\text{-}lb/lb_m\text{-}^oR$)
R_H	Radius at blade hub (in)
R_T	Radius at blade tip (in)
r	Radius (in)
S	Entropy ($BTU/lb\text{-}^oR$)
S^*	Non-dimensional entropy, S/c_p

T	Blade maximum thickness, see Fig. 6 (in)
T	Static temperature (^{o}R)
T_T	Total temperature (^{o}R)
TE	Thickness of blade trailing edge, in peripheral direction, see Fig. 6 (in)
TN	Thickness of blade trailing edge, in normal direction, see Fig. 6 (in)
t	Time (sec.)
u	Peripheral velocity (ft/sec)
V	Absolute velocity (ft/sec)
W	Relative velocity (ft/sec)
x	Non-dimensional radius, r/r_m
X_e	See eq. (30)
Y	Non-dimensional axial velocity, V_A/V_{Am}
Y	Total pressure loss coefficient, see eq. (40)
z	Number of blades

GREEK SYMBOLS

α	Absolute gas flow angle, see Fig. 5 (deg or radians)
β	Relative gas flow angle, see Fig. 5 (deg or radians)
β^*	Pressure ratio, see eq. (44)
β_o	Blade inlet angle, see Fig. 5 (deg or radians)
γ	Specific heat ratio
$\Delta\eta_{CL}$	Decrease in efficiency, due to rotor tip leakage, see eq. (47)
ΔR	Streamline displacement, see Fig. 1
δ_r	Streamline displacement, see Fig. 1
ζ	Kinetic energy loss coefficient
ζ^*	Kinetic energy loss coefficient used in the continuity equation, see eq. (28)
ζ_o	Kinetic energy loss coefficient for low Mach numbers, see eq. (42)
ζ_{CL}	Kinetic energy loss coefficient due to rotor tip leakage, see eq. (47)
η_{TS}	Total/static efficiency
η_{TT}	Total/total efficiency
θ	Angle between two radial planes (deg. or radians)
λ	Angle between the flow and the axis of the turbine in a meridional plane (deg. or radians)
μ	Gas viscosity (lb/sec-ft)
ξ	Area restriction factor, see eq. (27)
ρ	Gas density (lb_m/ft^3)
Φ	Non-dimensional flow function
X_ρ	Coefficient in Traupel's method of loss correlation, see eq. (46)
$\vec{\omega}$	Angular velocity (radians/sec)

SUBSCRIPTS

A	Axial
E	Equivalent
is	Isentropic expansion from total inlet conditions
m	Mean streamline
m	Meridional
R	Rotor
r	Radial direction, cylindrical coordinates
S	Stator
z	Axial direction, cylindrical coordinates
θ	Peripheral direction, cylindrical coordinates
o	Station ahead the stator
1	Station between stator and rotor
2	Station after the rotor

INTRODUCTION

An accurate knowledge of performance achievable with turbines of fixed geometry, both at design and off-design conditions, is important in advanced propulsion and power systems. The more accurate the prevision is, the more meaningful the optimization of the turbine itself and of the overall system will be.

A first way to solve this problem consists in the testing of a prototype, but it presents several disadvantages, namely it is expensive and time consuming. Furthermore, if effects of turbine geometry changes have to be investigated, different prototypes will be required.

An alternative solution to the problem consists in theoretical methods of prediction. The present availability of high speed computers allows one to solve systems of differential equations and to perform a large number of iterations in a short time. Moreover computer programs give the possibility of changing imput data, so that a large variety of different turbine configurations and of working conditions can be investigated.

This report presents a computer program, derived by the three-dimensional calculation method given first by Vavra [1] and then developed by Eckert [2] and Harrison [3]. This method takes account of enthalpy and entropy gradients and of streamline curvatures and slopes in equations of motion, and of boundary layer thicknesses in continuity equation. It is applicable to single-stage axial turbines with unchocked flow.

A critical point in all theoretical performance calculations is the prediction of the losses that occur in the blade rows. In the present program, one can choose among five different loss correlation methods. For each method pertinent subroutines compute loss coefficients from blading geometry and flow characteristics. A comparative study of these methods can be found in [4], where they were applied to actual turbines of different design practices, in a wide range of all significant flow and geometrical properties.

The comparisons presented in [4] with experimental performance showed a fair agreement of predictions with all turbine stages that were examined.

The present report is divided into four sections: in the first the used equations are set up and necessary assumptions are discussed; in the second the method of solution is described; in the third different losses and discharge flow angles available prediction methods are described; and in the fourth the instructions for the use of computer program are given, with an example of imput and output data. Eventually in the appendix the FORTRAN list of the MAIN routine and of the 28 subroutines is given.

METHOD OF ANALYSIS

The flow in turbomachines is ruled by the three fundamental laws of fluid dynamics, namely:

Equation of Motion

Energy Equation

Equation of Continuity.

All proper three-dimensional calculation methods proposed in the technical literature solve the differential equations derived by these laws. Differences among these methods are due to the three following reasons:

- different stations are chosen where equations are solved;
- different hypotheses are formulated to describe the real processes occurring in the machine;
- different numerical methods are applied in the solutions of the equations.

As far as the first problem is concerned in the present method, the equation of motion is applied at three stations, namely ahead of the stator, after the stator, and after the rotor, indicated respectively with subscripts 0, 1, 2 in Fig. 1. On the contrary, since blade geometry is given, the continuity equation is applied at blade throat sections 1* and 2* in Fig. 1, as suggested in [5].

those occurring in the boundary layers along the blade surfaces, and flow frictional losses between blades can therefore be neglected.

Assumption 4) is reasonable for uncooled blades, where energy changes due to heat transfer are negligible with respect to those related to velocity changes. If blades are cooled, the additional term q in the energy equation must be specified. Assumption 5) is valid in most cases. If the thermodynamic processes occur in ranges where real gas effects are not too strong, average values of gas properties give good approximations.

Some additional assumptions, regarding streamlines slope and curvature, are discussed in the section pertaining to the equation of motion.

As far as the third problem is concerned, the numerical small difference method was found to give a good convergence, and was therefore applied for the solution of the differential equations.

The following sections give the derivations of the equations with the above-listed assumptions.

Equation of motion

The general equation of motion for relative flow in vectorial form, is:

$$\frac{\partial \vec{W}}{\partial t} + \nabla H_R = \vec{W} \times (\nabla \times \vec{W} + 2\vec{\omega}) + T \nabla S + \vec{f}_f \qquad (1)$$

For absolute flow, where $\begin{cases} \vec{\omega} = 0 & (2) \\ \vec{v} = \vec{W} & (3) \\ H = H_R & (4) \end{cases}$, equation (1)

becomes:

$$\frac{\partial \vec{V}}{\partial r} + \nabla H = \vec{V} \times (\nabla \times \vec{V}) + T \nabla S + \vec{f}_f \qquad (1a)$$

With hypothesis 1) $\frac{\partial \vec{W}}{\partial t} = 0$, $\frac{\partial \vec{V}}{\partial t} = 0$

and hypothesis 2) $\vec{f}_f = 0$

This allows one to more accurately evaluate the pressure drops occurring in blade channels, since in this way it is possible to account for boundary layer thicknesses. This problem is particularly important at high Mach numbers where a small change in flow area causes large differences in pressure ratios.

As far as the second problem is concerned, the following assumptions are made:

1) Steady flow

2) Frictionless flow at the stations where the equations of motion are solved.

3) Axisymmetric flow at the stations where the equations of motion are solved.

4) Adiabatic flow.

5) The working fluid is a perfect gas, namely a gas having the equation of state:

$$p = \rho R_G T$$

and specific heat at constant pressure is independent of temperature and pressure.

Hypotheses 1) and 3) are interrelated since the flow can be steady in both rotor and stator only if it is axisymmetric. Although they are correct only for cascades with an infinite number of blades, axisymmetry and steady conditions are necessary assumptions since any other hypothesis would require unknown quantitative information on flow inside the blade rows. One problem connected with these assumptions is that downstream conditions cannot affect the flow upstream. Therefore pressure distributions at rotor exit can deviate from those imposed by the discharge conditions.

With assumption 2), all entropy changes are supposed to occur in the blade rows ahead of the considered station. This assumption can be justified by the fact that velocity gradients in the regions, where the equation of motion is applied, are in all probability smaller than

equations (1) and (1a) become respectively:

$$\nabla H_R = \vec{W} \times (\nabla \times \vec{W} + 2\vec{\omega}) + T \nabla S \qquad (5)$$

$$\nabla H = \vec{V} \times (\nabla \times \vec{V}) + T \nabla S \qquad (5a)$$

The following derivations for equation (5) are valid also for equation (5a), if substitutions (2), (3), (4) are performed.

It is convenient to express equation (5) in cylindrical coordinates (see Fig. 1 for symbols). Equating the three components of equation (5), the following equations are obtained:

a. tangential component:

$$\frac{1}{r}\frac{\partial H_R}{\partial \theta} = \frac{W_A}{r}\left[\frac{\partial W_A}{\partial \theta} - \frac{\partial (rW_u)}{\partial z}\right] - \frac{W_r}{r}\left[\frac{\partial (rW_u)}{r} - \frac{\partial W_r}{\partial \theta}\right] - 2\omega W_r + \frac{T}{r}\frac{\partial S}{\partial \theta} \qquad (6)$$

b. meridional component:

$$\frac{\partial H_R}{\partial z} = W_r\left[\frac{\partial W_r}{\partial z} - \frac{\partial W_A}{\partial r}\right] - \frac{W_u}{r}\left[\frac{\partial W_A}{\partial \theta} - \frac{\partial (rW_u)}{\partial z}\right] + T\frac{\partial S}{\partial Z} \qquad (7)$$

c. radial component:

$$\frac{\partial H_r}{\partial r} = \frac{W_u}{r}\left[\frac{\partial (rW_u)}{\partial r} - \frac{\partial W_r}{\partial \theta}\right] - W_A\left[\frac{\partial W_r}{\partial z} - \frac{\partial W_A}{\partial r}\right] + 2\omega W_u + T\frac{\partial S}{\partial r} \qquad (8)$$

with hypothesis 3) $\frac{\partial}{\partial \theta}(\ \ ) = 0$

and hypothesis 4) $\vec{w}\ d\ t \cdot \nabla H_R = 0$

the system of equations (6), (7), (8) reduces to equation (9):

$$\frac{\partial H_R}{\partial r} = \frac{W_u}{r}\frac{\partial (rW_u)}{\partial r} - W_A\frac{\partial W_r}{\partial z} + W_A\frac{\partial W_A}{\partial r} + 2\omega W_u + T\frac{\partial s}{\partial r} \qquad (9)$$

Using substitution: $H_E = H_R + \frac{u^2}{2}$ (10)

with hypotheses 5) $H = c_p T$ and 4) $H_E = \text{const}$ (see Fig. 2)

$$T_2 = \frac{H_E}{c_p} - \frac{W_2^2}{2c_p} \tag{11}$$

and introducing the non-dimensional quantities:

$$Y = \frac{W_A}{W_{Am}} \tag{12}$$

$$X = \frac{r}{r_m} \tag{13}$$

$$S^* = \frac{S}{c_p} \tag{14}$$

Equation (9) becomes:

$$\frac{1}{Y^2}\frac{\partial Y^2}{\partial x} + \cos^2\beta\left(-\frac{2r_m}{W_A}\frac{\partial W_r}{\partial z} - \frac{1}{\cos^2\lambda}\frac{\partial S^*}{\partial x}\right) + 2\tan\beta\frac{\partial \beta}{\partial x}$$

$$+ \frac{2}{x}\sin^2\beta + \frac{4\sin\beta\cos\beta}{W_{Am}\,Y} + \frac{2U_m U\cos^2\beta}{W_A^2 Y^2} - \frac{2\cos^2\beta}{W_{Am}^2 Y^2}\frac{\partial H_E}{\partial x} +$$

$$+ \left[\frac{2H_E\cos^2\beta}{W_{Am}^2 Y^2} - \sin^2\beta\right]\frac{\partial S^*}{\partial x} = 0 \tag{15}$$

In this equation, terms containing $\cos\lambda$ and $\frac{\partial W_r}{\partial z}$ depend respectively on streamlines slope and curvature. Vavra [1] showed that the most reasonable assumptions, when only three points of a streamline are known, are the following (see Fig. 1 for symbols):

$$\frac{1}{W_A}\frac{\partial W_r}{\partial z} = \pm k\frac{\delta_r}{L^2} \tag{16}$$

$$\cos^2\lambda = \frac{L^2}{L^2 + (\frac{\Delta R}{2})^2} \tag{17}$$

In equation (16) the positive sign holds for station (2) and the negative one for station (1), for δr positive as shown in Fig. 1. Suggested values for k are between 4 and 6. Finally with equations (16) and (17) into (15) the following equation is obtained:

$$\frac{d\,(\ln Y^2)}{dx} = -\cos^2\beta \left[2\,k\,r_m \frac{\delta r}{L^2} - \frac{L^2 + (\frac{\Delta R}{2})^2}{L^2} \frac{dS^*}{dx} \right]$$

$$- 2 \tan\beta \frac{d\beta}{dx} - \frac{2}{x}\sin^2\beta - \frac{4\,U_m \sin\beta \cos\beta}{W_{Am}\,Y} -$$

$$- \frac{2\,U_m\,U\cos^2\beta}{W_{Am}^2\,Y^2} + \frac{2\cos^2\beta}{W_{Am}^2\,Y^2}\frac{dH_E}{dx} - \left[\frac{2\,H_E\cos^2\beta}{W_{Am}^2\,Y^2} - \sin^2\beta \right] \frac{dS^*}{dx} \qquad (18)$$

For the station after the stator row, the following equation can be derived with (2), (3) and (4) in equation (18):

$$\frac{d(\ln Y^2)}{dx} = -\cos^2\alpha \left[(-2\,K\,r_m \frac{\delta r}{L^2}) - \frac{L^2 + (\Delta R/2)^2}{L^2} \frac{dS^*}{dx} \right] -$$

$$-2\tan\alpha_1 \frac{d\alpha}{dx} - \frac{2}{x}\sin^2\alpha_1 + \frac{2\cos^2\alpha}{Y^2\,V_{Am}^2}\frac{dH}{dx} - \left[\frac{2\,H\cos^2\alpha}{Y^2\,V_{Am}^2} - \right.$$

$$\left. - \sin^2\alpha_1 \right] \frac{dS^*}{dx} \qquad (18a)$$

Equation(18a) could also have been derived directly from equation (5a).

In equations (18) and (18a) the last term is depending on flow irreversibilities due to frictional losses. The specific entropy S* will be calculated, after [1], by:

$$S^* = \ln\left[\frac{\dfrac{Y^2\,W_{Am}^2}{2\,H_E\cos^2\beta}}{1 - \dfrac{Y\,W_{Am}^2}{2\,H_E\cos^2\beta\,(1-\zeta)}} \right] + S_E^* \qquad (19)$$

and by:

$$S^* = \ln \left[\frac{\frac{\gamma^2 V_{Am}^2}{2 H_o \cos^2\beta}}{\frac{\gamma V_{Am}^2}{2 H_o \cos^2\beta (1-\zeta)}} \right] + S_o^* \qquad (19a)$$

where ζ represents the kinetic energy loss coefficient which is established by the chosen loss correlation method.

Energy equation

The energy equation in a relative flow is given by:

$$\vec{W}dt \cdot \nabla (H_R) = \vec{W}dt \cdot \nabla(q) - \frac{\partial}{\partial t} \left(\frac{W^2}{2}\right) dt \qquad (20)$$

and in an absolute flow, with (2), (3) and (4) in (20), :

$$\vec{V}dt \cdot \nabla (H_R) = \vec{V}dt \cdot \nabla(q) - \frac{\partial}{\partial t} \left(\frac{V^2}{2}\right) dt \qquad (20a)$$

where q is the heat added to a unit mass particle from external sources. With assumptions 1) $\partial/\partial t(\ ) = 0$ and 4) $q = 0$, equations (20) and (20a) become:

$$\vec{W}dt \cdot \nabla (H_R) = 0 \qquad (21)$$

$$\vec{V}dr \cdot \nabla (H) = 0 \qquad (21a)$$

Equations (21) and (21a) indicate that for steady, adiabatic flow the relative total enthalpy is constant along any streamline. This does not mean that $\nabla (H_R) = 0$, since relative total enthalpy can assume different values for different streamlines.

Equation of continuity

Pressure ratios across a stage necessary to discharge a given flow rate are function of inlet Mach number, blade openings and the losses occurring in the blades. For an isentropic flow the mass flow rate passing thru a section dA_n perpendicular to the flow is given by:

$$d\dot{m}_{is} = \rho_{is} V_{is} \, dA_n \tag{22}$$

where ρ_{is} and V_{is} are respectively the density and the velocity corresponding to an isentropic process. It can be shown that equation (22) can be expressed for a perfect gas (see assumption 5) by:

$$d\dot{m}_{is} = \frac{P_T}{\sqrt{R_G T_T}} \Phi \, dA_n \tag{23}$$

where P_T, T_T are, respectively, total pressure and total temperature (constant for isoentropic and adiabatic flows) and Φ is a function of pressure ratio and gas isentropic exponent, namely:

$$\Phi = \sqrt{\frac{2\gamma}{\gamma-1}\left[\left(\frac{P}{P_T}\right)^{2/\gamma} - \left(\frac{P}{P_T}\right)^{\frac{\gamma+1}{\gamma}}\right]} \tag{24}$$

With the symbols in Fig. 3, assuming the pressure to be constant along the throat "a" equation (23) becomes:

$$d\dot{m}_{is} = \frac{P_T}{\sqrt{R_G T_T}} \Phi \, a \cos\lambda \, d r \tag{25}$$

Integrating equation (25) along the radius and for z blades the flow rate passing thru the stage is:

$$\dot{m}_{is} = z \int_{R_H}^{R_T} \frac{P_T}{\sqrt{R_G T_T}} \Phi \, a \cos\lambda \, dr \tag{26}$$

In actuality, the flow rate will be less than $\dot{m}_{is}$, because of the losses occurring in the blade channels.

A so-called restriction factor:

$$\xi = \frac{d\dot{m}}{d\dot{m}_{is}} \tag{27}$$

is now introduced.

In [5] the following relationship between ξ and the kinetic energy loss coefficient ζ^* is derived:

$$\xi = \frac{1}{1 + \zeta^* \frac{H}{K}} \tag{28}$$

where H and K are respectively the boundary layer wake form factor and the energy factor. For boundary layer profiles following the power law, the ratio $\frac{H}{K}$ can be expressed in power series:

$$\frac{H}{K} = \frac{1 - (1-Xe) \sum_{1}^{\infty} \left[Xe^{i-1}/1+(2i-1)m \right]}{(1-Xe) \sum_{1}^{\infty} i \left[Xe^{i-1}/1+(2i-1)m \right] - (1-Xe) \sum_{1}^{\infty} i \left[Xe^{i-1}/1+(2i+1)m \right]} \tag{29}$$

where:

$$Xe = 1 - (P/P_T)^{\gamma-1/\gamma} \tag{30}$$

and m is the exponent of the power law for the boundary layer profile (for incompressible flow, m depends on Reynolds number and varies between 1/7 and 1/10). Experience has shown that the loss coefficient ζ^* has to be taken less than the value ζ_{TOT} that corresponds to the overall energy losses that are given by the correlation methods. In the present program one of the three following different assumptions for ζ^* can be chosen: 1) $\zeta^* = \zeta_{TOT}$; 2) $\zeta^* = \frac{1}{2}\zeta_{TOT}$; 3) $\zeta^* = \zeta_{PROFILE}$.

While assumption 1) is certainly conservative, it is difficult to state which of assumptions 2) or 3) is the best one. Good agreement between experimental values and predicted flow rates for all considered turbines at low tip clearance values was found in [4], where assumption 2) was adopted. Assumption 3) was however found in closer agreement with test data for large values of rotor tip clearances.

Tip leakage flow rate will be calculated by using the relation:

$$\dot{m}_{CL} = \frac{1}{K_{CL}} \left(\xi \frac{P_T}{\sqrt{R\ T_T}} \Phi \cos \lambda\right)_{TIP} A_{CL} \tag{31}$$

where: $A_{CL} = 2\pi R_H c\ell$ (32)

Since the flow is not perpendicular to the leakage area, and since the restriction factor ξ_{TIP} does not account for boundary layer blockage occurring on shroud, the leakage flow rate must be divided by a coefficient K_{CL} (larger than 1), assumed equal to 2 in the present program.

With equations (29) and (33), the overall flow rate passing thru a blade row is given by:

$$\dot{m}_{TOT} = \dot{m} + \dot{m}_{CL} = z \int_{R_H}^{R_T} \xi \frac{P_T}{\sqrt{R_G\ T_T}} \Phi\ a \cos \lambda\ dr + \frac{1}{K_{CL}} \left(\xi \frac{P_T}{\sqrt{R\ T_T}} \Phi \cos\lambda\right)_{TIP} A_{CL} \tag{33}$$

Equation (33) can be expressed in the following dimensionless form:

$$\dot{m} = z\ R_m\ a_m \int_{x_H}^{x_T} \left(\xi \frac{P_T}{\sqrt{R_G\ T_T}} \Phi\ \bar{a} \cos \lambda\right)_x dx + \frac{2\pi}{K_{CL}} \xi_{TIP} \frac{x_T}{x_m} \frac{c\ell}{z\bar{a}} \left(\frac{P_T}{\sqrt{R\ T_T}} \Phi \cos\lambda\right)_{TIP} \tag{34}$$

where $\bar{a} = \frac{a}{a_m}$ (35)

METHOD OF SOLUTION

Since no direct solution of governing equations is possible, an iterative method is followed. At first, solutions are found without considering the influence of streamline curvature and slope. The derived radial shifts are then used for the second and final cycles of calculation. In Fig. 4 the scheme followed in the computer program is indicated. The names in brackets correspond to the names of the subroutines which perform the operations described next to the brackets.

The flow ahead of the stator is supposed to be uniform, so that the radii of streamlines dividing the flow rate in equal parts can be easily computed. For stator and rotor rows the following functions are supposed to be known:

STATOR	ROTOR
$\alpha_1 = \alpha_1$ (r, flow condition)	$\beta_2 = \beta_2$ (r, flow condition)
$a_1 = a_1$ (r)	$a_2 = a_2$ (r)
$\zeta_s = \zeta_s$ (r, flow condition)	$\zeta_R = \zeta_R$ (r, flow condition)

All derivatives used in the following analysis are computed by finite difference methods. The computer program calculates flow conditions along 5 streamlines. However the same scheme of calculation can be applied to any number of streamlines. By assuming the inlet Mach number M_o, the flow rate passing thru section 0 can easily be determined. Radial position of streamlines at station 1, R_1, and the axial velocity at mean streamline, V_{Alm}, are also assumed a priori, and will be checked later.

For any given values of V_{Alm}, ΔR, and δr, equation (18a) can be solved by iteration. In fact it can be reduced to:

$$\frac{d(\ell n\, Y^2)}{dx} = I\,(x) \tag{36}$$

Equation (36) integrated, with boundary condition $\begin{cases} x = 1 \\ y = 1 \end{cases}$ (37) gives:

$$\ln Y^2 = \int_1^x I\, dx \tag{38}$$

and

$$Y = e^{\frac{1}{2}\int_1^x I\, dx} \tag{39}$$

Solutions are found by trial and error, assuming approximate values of Y(x) and verifying equation (39). Once equation (39) has been solved, all flow conditions at station (1) are known and the overall continuity equation (34) can be solved. If the calculated flow rate is different from the assumed one, V_{aml} will be changed and the iteration shown in Fig. 4 is performed. When overall continuity equation is satisfied, the assumed radial position of streamlines is checked, and necessary iterations are performed. If streamlines continuity is met also, the flow at the rotor inlet is known completely. A similar iterative method is then followed for station 2 after the rotor as indicated in Fig. 4. If the flow after the rotor is known also, the radial shift of the streamlines can be determined, and the whole calculating procedure is repeated by taking account of the streamlines curvatures and the slopes in solving the equation of motion.

Eventually the resulting average pressure ratio across the turbine is compared with the desired one, and if the difference is larger than a smallprefixed error, the complete calculating scheme is repeated again with a new value of inlet Mach number. After the specified pressure ratio has been obtained, all output information is calculated and printed.

FLOW ANGLES AND LOSS COEFFICIENTS CORRELATIONS

Evidently, even the most accurate method of performance prediction will give results in disagreement with actuality, if the flow angles and/or the losses in the blade rows are not predicted with the necessary accuracy.

Several correlations, either empirical or theoretical, have been proposed in the technical literature. A comparative study of five correlations methods available in the present program can be found in Reference [4]. The purpose of the present chapter is not to discuss the applicability of these different correlations, but only to indicate the problems which arose, in applying the different correlation methods. In Fig. 5 the nomenclature and sign convection of the velocity triangles is indicated. Unless otherwise stated, the variables are positive if directed as in Fig. 5. In Fig. 6 the blading geometry characteristics used in the different correlation methods are indicated. The names

given in Fig. 6 are the FORTRAN names used in the program for stator quantities at the mean radius.

The program is organized in such a way that other than considered flow angles and loss coefficients correlations can be introduced by adding a few cards and pertinent subroutines. Since the solution method is iterative, added subroutines can use blading and flow characteristics that are not used in the present program.

a) Flow angles correlations

Two methods, one given by Ainley and Mathieson [6] and the other given by Traupel [10] are available in subroutines. In both these methods, exit flow angles (α_1, β_2)are considered to be independent on inlet angles (α_0, β_1). While in Traupel's method the angles are a function of blading geometry only, in A&M method also the exit Mach number is supposed to affect the angles. Although both these methods are given for a "reference diameter approach", they will be applied in three-dimensional calculations with the assumption that at any radius the angle is related only to the corresponding characteristics. Since during the calculations both Mach numbers and streamlines radii will be changed, flow angles corrections are automatically performed during the solution of the equation of motion.

b) Loss coefficients correlations

The assumption is made that at any particular radius the loss coefficient is a function of the characteristics at that radius only. It is realized that this assumption is not realistic, since secondary and leakage losses are certainly not equally distributed along the radius. On the other hand, secondary and tip leakage flows are not understood well enough at the present time to formulate any other reasonable assumption.

Five loss correlation methods given in Ref. [6-10] are available in subroutines. They calculate loss coefficients from given blade geometry and flow angles and velocities.

The first considered method is the Ainley and Mathieson [6] method. Recently an improvement to the original method was given by Dunham and Came [7]. Both methods are available in subroutines. These methods express losses by total pressure loss coefficient Y,

defined by:

$$Y = \frac{P_{To} - P_t}{P_t - p} \tag{40}$$

and assume Y to be independent on pressure ratio P_{To}/p. The relationship between the kinetic energy loss coefficient ζ and Y is given by:

$$\zeta = \frac{\left[\frac{1+Y}{1+Y\ p/P_{To}}\right]^{\frac{\gamma-1}{\gamma}} - 1}{\left(\frac{1}{p/P_{To}}\right)^{\frac{\gamma-1}{\gamma}} - 1} \tag{41}$$

The assumption that Y is constant implies that ζ decreases with increasing Mach number. Since this behavior is not experimentally proved, two alternatives to equation (41) are available in the program. In both these alternatives ζ is supposed to be constant with pressure ratio, and assumes respectively the value corresponding to very low Mach numbers (eq. 42) or to an exit Mach number of 0.8 (eq. 43).

$$\zeta = \zeta_o = \lim_{p/P_{To} \to 1} \zeta = \frac{Y}{1+Y} \tag{42}$$

$$\zeta = \zeta_{M=.8} = \frac{\left[\frac{1+Y}{1+Y\cdot\beta^*}\right]^{\frac{\gamma-1}{\gamma}} - 1}{(1/\beta^*)^{\frac{\gamma-1}{\gamma}} - 1} \tag{43}$$

where β^* is the pressure ratio corresponding to an isentropic Mach number of 0.8, given by:

$$\beta^* = \left[1 + \frac{\gamma-1}{2} \times .8^2\right]^{-\frac{\gamma}{\gamma-1}} \tag{44}$$

The same alternatives are given also for the simple method of Lenherr and Carter [9].

For the method of Balje' [8], the boundary layer wake form factor H must be introduced.

With the same nomenclature and assumptions as in eq. (29), H can be expressed by:

$$H = \frac{1 - (1-X_e) \sum_{1}^{\infty} i \left(\frac{X_e^{i-1}}{1+m\,(2i-1)} \right)}{- (1-X_e) \sum_{1}^{\infty} i \left(\frac{X_e^{i-1}}{1+m(2i)} \right) + (1-X_e) \sum_{1}^{\infty} i \left(\frac{X_e^{i-1}}{1+m(2i-1)} \right)} \qquad (45)$$

In this program the assumption m = 0.15 is made. If another exponent has to be introduced, card #17 must be changed in the MAIN routine.

In Traupel's method, the loss coefficients depend on the coefficient:

$$X_p = X_p \text{ (Re, relative surface roughness, turbulence factor).} \qquad (46)$$

In the present program, the standard value of X_p=1 is assumed. If the considered turbine has peculiar values of surface roughness or Reynolds numbers, it will be necessary to change card #15 in the MAIN routine.

For conformity with the other methods, tip clearance losses are expressed by the kinetic energy loss coefficient ζ_{CL}, instead of by the overall efficiency decrease $\Delta\eta_{CL}$ as in [10]. The relationship between $\Delta\eta_{CL}$ and ζ_{CL} is given by:

$$\zeta_{CL} = (1-\zeta_r) \times \left[1 - \left(1 - \frac{\Delta h_{is}\, \Delta\eta_{CL}}{u_2\, W_{w2}} \right)^2 \right] \qquad (47)$$

where Δh_{is} is the isentropic enthalpy drop through the turbine and ζ_r is the rotor kinetic energy loss coefficient for zero tip clearance.

The present computer program is composed of a MAIN routine and 28 subroutines, eight of which are concerned with flow calculations, two with flow angle correlations, 15 with blade loss correlations, and three with numerical interpolations. A brief description of the purpose of each routine is given below.

a) MAIN routine

1. The primary function of the MAIN routine is to control the overall logic of the computer program which is indicated in Fig. 4. Furthermore the imput data are read, numerical constants are introduced, interpolations concerning stall and blade angles and flow areas are performed and the flow angles are computed. Eventually, also the output data are printed.

b) Flow calculation subroutines

2. In subroutine CHAN the flow rate passing through the section 0 is calculated from the conditions ahead of the stator.

3. In subroutine STATØR the equation of motion (18a) is solved, and the flow conditions after the stator are calculated. If necessary, new values of the flow angles are also calculated.

4. In subroutine RØTØR1 the absolute flow properties calculated in STATØR are converted into relative properties at rotor inlet.

5. In subroutine RØTØR2 the equation of motion (18) is solved, and the flow conditions after the stator are calculated. If necessary, also new values of flow angles are calculated.

6. In subroutine FLØWR the flow rate passing through the blade sections, either at station 1 or 2, is computed by equation (34), and compared with the value calculated in CHAN. If the difference is larger than a small prefixed error, a new value of the axial velocity at the mean stremaline is computed. The fractional values of the flow rate passing between the hub and each streamline are calculated also.

7. In subroutine SLINE the fractional values of the flow rate computed in FLØWR are compared with prefixed ones. If the differences are larger than a small specified error, new values of the streamline radii, either at station 1 or 2, are computed.

8. In subroutine ALØS1 the stator loss coefficients are calculated from the chosen loss correlation, as a function of blading geometry and flow characteristics. Coefficients ζ^* of (28) are computed for the stator blades.

9. In subroutine ALØS2 the rotor loss coefficients are calculated from the chosen loss correlation as function of blading geometry and flow characteristics. Coefficients ζ^* of equation (28) are computed for the rotor blades.

c) Flow Angles Subroutines

10. In subroutine ANGAIN the flow angles are computed from blading geometry and exit Mach numbers with the method of Ainley and Mathieson [6].

11. In subroutine ANGTRA the flow angles are computed from blading geometry with Traupel's method [10].

d) Loss Correlation Subroutines

The six subroutines given below are concerned with the methods [6] and [7].

11. In subroutine CØEFFI the imput cards concerning the profile losses of nozzle blades given in [6] are read, and the necessary interpolations are performed.

12. In subroutine CØEFF2 a similar process is followed for the profile losses of impulse blades.

13. In subroutine CALYAØ the profile losses of nozzle blades are calculated with the coefficients computed in CØEFFI.

14. In subroutine CALYA2 the profile losses of impulse blades are calculated with the coefficients computed in CØEFF2.

15. In subroutine FIG6 the necessary interpolations for calculating the secondary losses are performed.

16. In subroutine AINLØS the overall loss coefficients with either method [6] or [7] are calculated from blading geometry and flow angles. Subroutine AINLØS must be called after subroutines CØEFFI and CØEFF2, and calls subroutines CALYAØ, CALYA2 and FIG6.

The eight subroutines given below are concerned with method (11) of the loss correlation.

17. In subroutine TRAUP1 the imput cards concerning the profile losses given by Traupel's method are read, and the necessary interpolations are performed.

18. In subroutine XPØ the basic profile loss coefficients are computed with the coefficients calculated in TRAUP1.

19. In subroutine CSIM Mach number effects on the loss coefficients are computed.

20. In subroutine CID the effects due to the trailing edge thichness and nontwisted blades on the loss coefficients are computed.

21. In subroutine CSIW the end wall loss coefficients are computed.

22. In subroutine CSIR the secondary loss coefficients are computed.

23. In subroutine ALEAK the tip leakage efficiency losses are computed.

24. In subroutine TRAUP2 the overall loss coefficients are computed with Traupel's method [10] from both blade geometry and flow characteristics. Subroutine TRAUP2 has to be called after TRAUP1, and calls subroutines XPØ, CSIM, CID, CSIW, CSIR and ALEAK.

25. In subroutine ZALLØS the overall loss coefficients are computed with the method of Lenherr and Carter [9] from the flow angles and the relative velocities.

26. In subroutine BALJE the overall loss coefficients are computed with Balje's method [8] from blade geometry and flow conditions.

e) Numerical Interpolation Subroutines

27. In subroutine PARAB the coefficients of the parabolic interpolations used to approximate curves are calculated.

28. In subroutine CHBFT the coefficients of the polinomial of arbitrary degree, which is the best fit of a given array of points in the Chebyschev sense, are calculated.

29. In subroutine YC the value of the polynomial determined in CHBFT, corresponding to a given value of the independent variable, is calculated.

Description of Imput Data

The imput data of the present computer program consist of 63 + NSETS cards, NSETS being the number of conditions for which performance values are to be obtained. They can be divided in three sections. In the first, the constant values used in the methods of Ainley and Mathieson and of Traupel are introduced (these 36 cards are read respectively in subroutines CØEFFI, CØEFF2 and TRAUP1). In the second, the specifications about the detail of output desired, the tolerances of the numerical solutions, the systems of correlation of the flow angles and the loss coefficients, the coefficients used in the equation of continuity, the gas properties and the turbine geometry are stated. In the third, the conditions for which performance values are to be found are introduced.

The 36 input cards for the first section are given in Table I. They will remain unchanged for all turbines. Detailed description of the 27 cards composing the second section of the imput are given in Table II, where also a description of the third imput section can be found in cards #28 and #29. An example of the imput cards described in Table II is given in Table III.

Description of the normal output

In Table IV the output corresponding to the imput of Tables I and III is given. It can be seen that it consists of 1 + 3 NSETS sheets. In the first sheet the turbine geometrical dimensions and the choice among the different correlation methods are described. Then three sheets for every set of operating conditions are printed. The first of these sheets describes the flow conditions at station 1 after the stator row; the second one the flow conditions after the rotor row; and the third one gives the main overall turbine characteristics and the mass averaged performance values.

ACKNOWLEDGEMENTS

The author would like to express his appreciation to Dr. M. H. Vavra for providing guidance and counsel during the investigation.

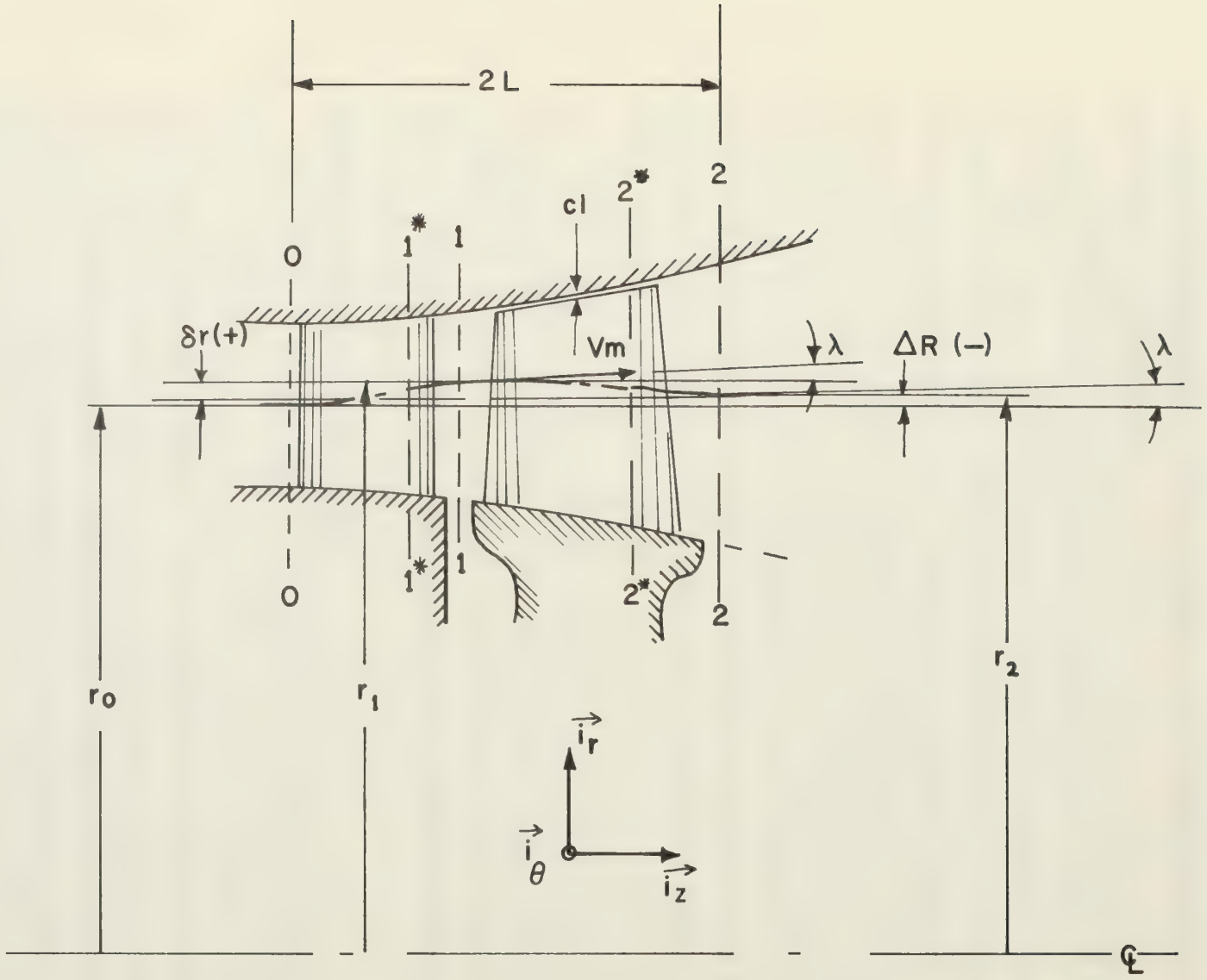


Fig . 1 Coordinates, stations and streamline nomenclature.

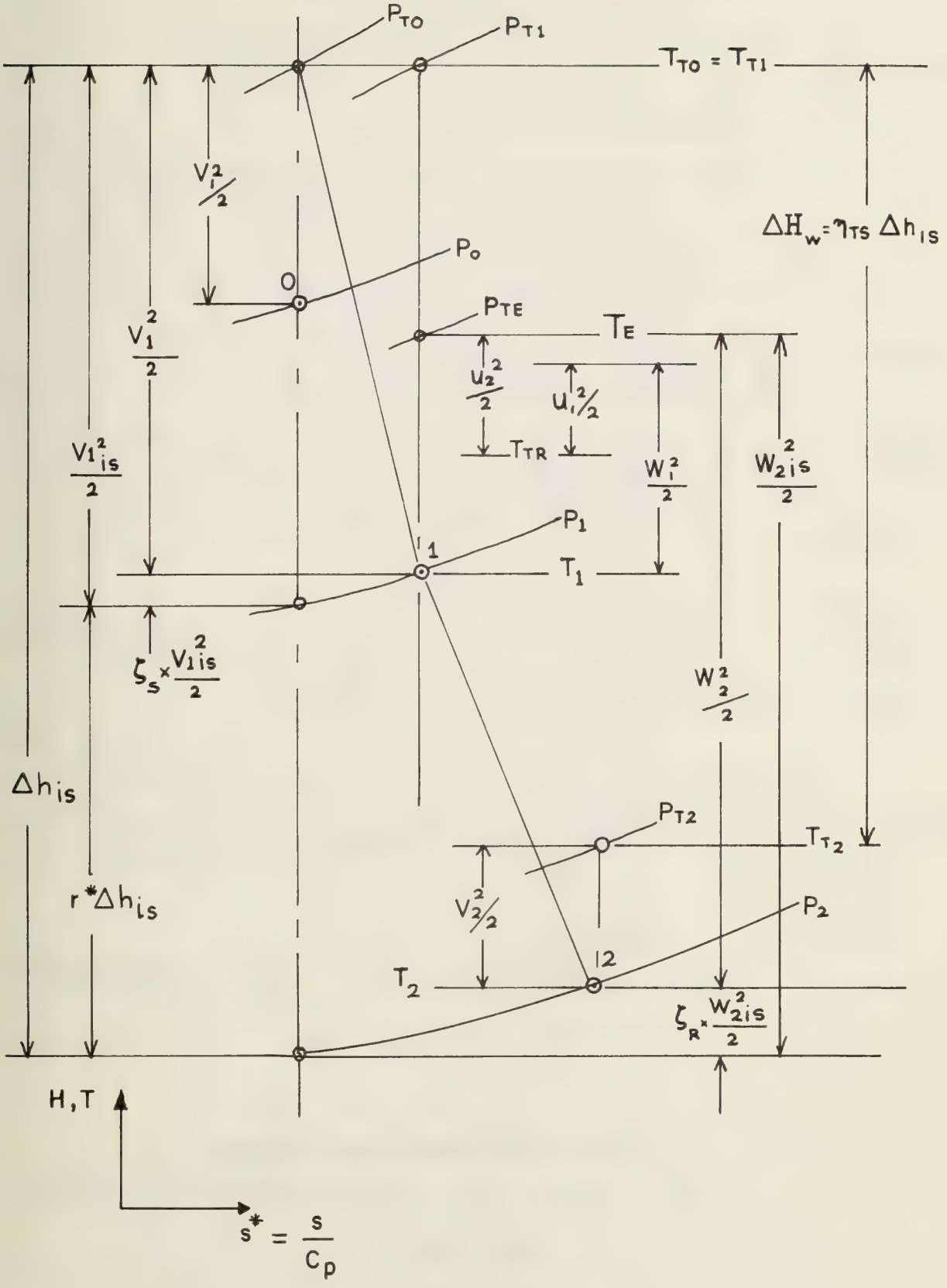


Fig. 2— Turbine thermodynamic process.

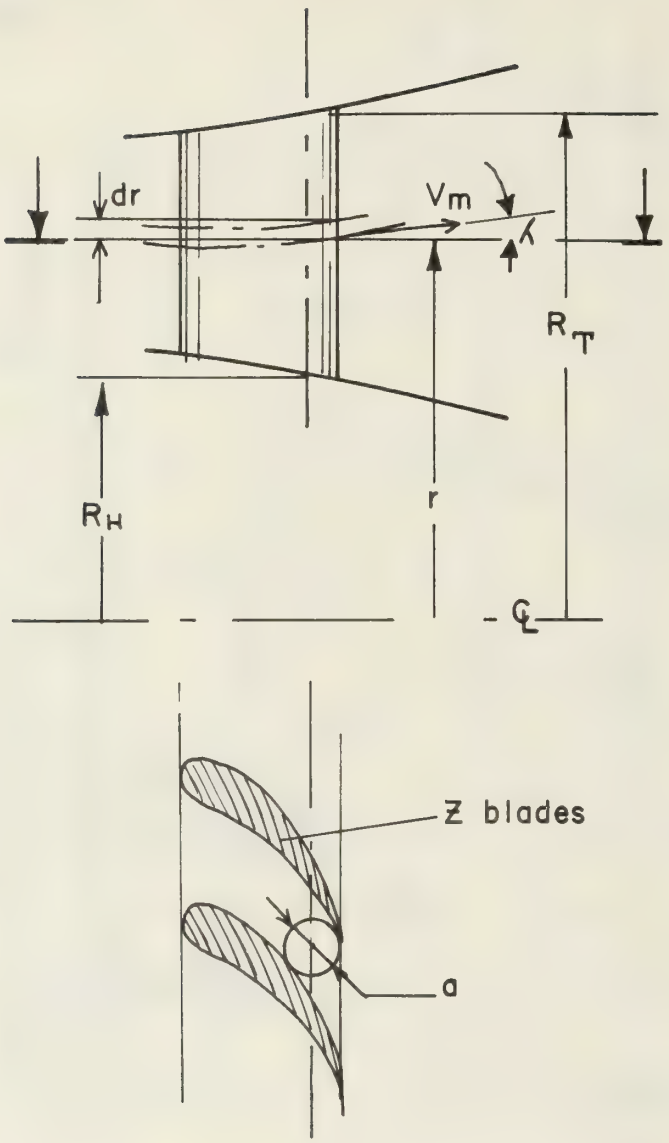


Fig. 3 Symbols in continuity equation.

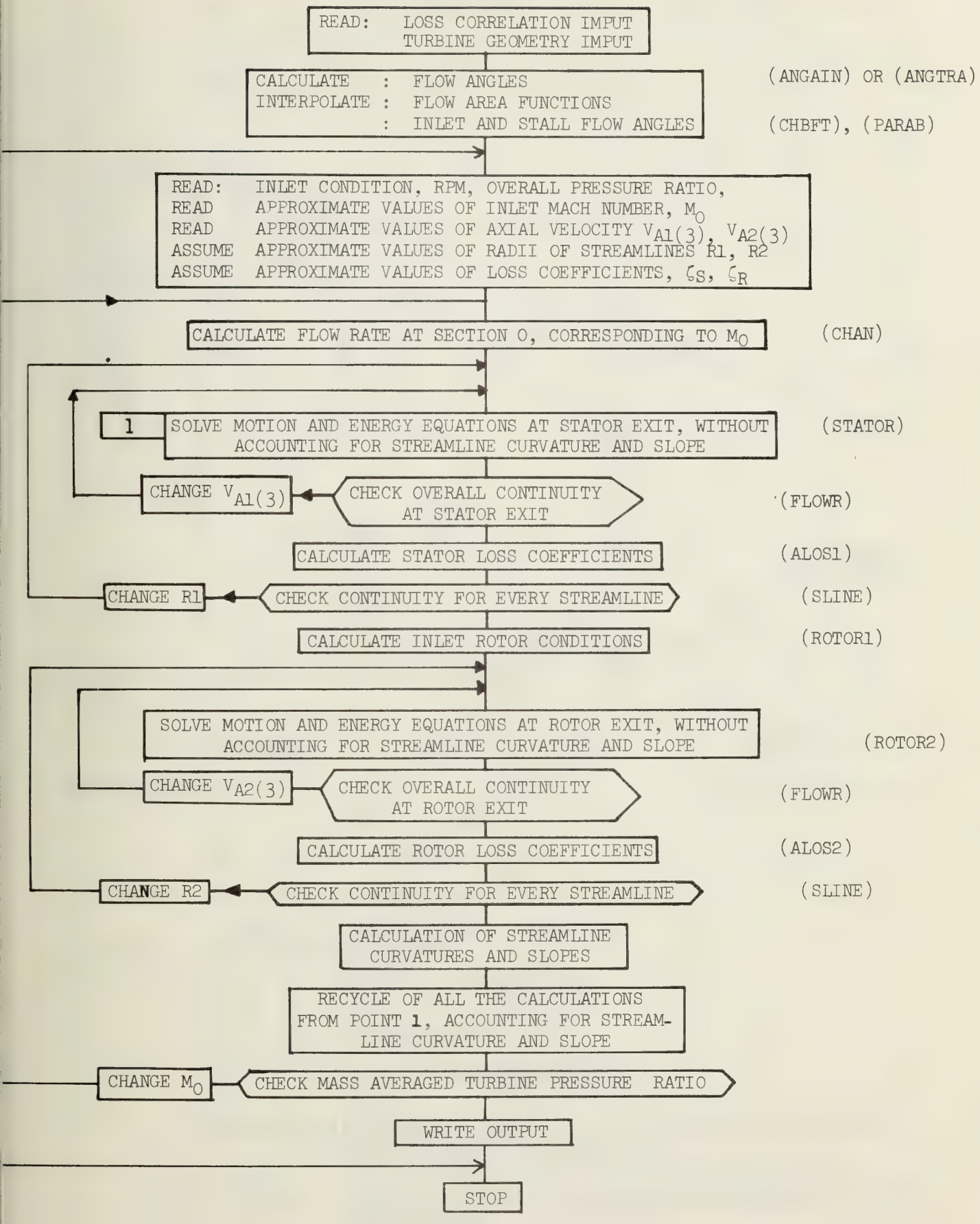


Fig. 4 Flow diagram

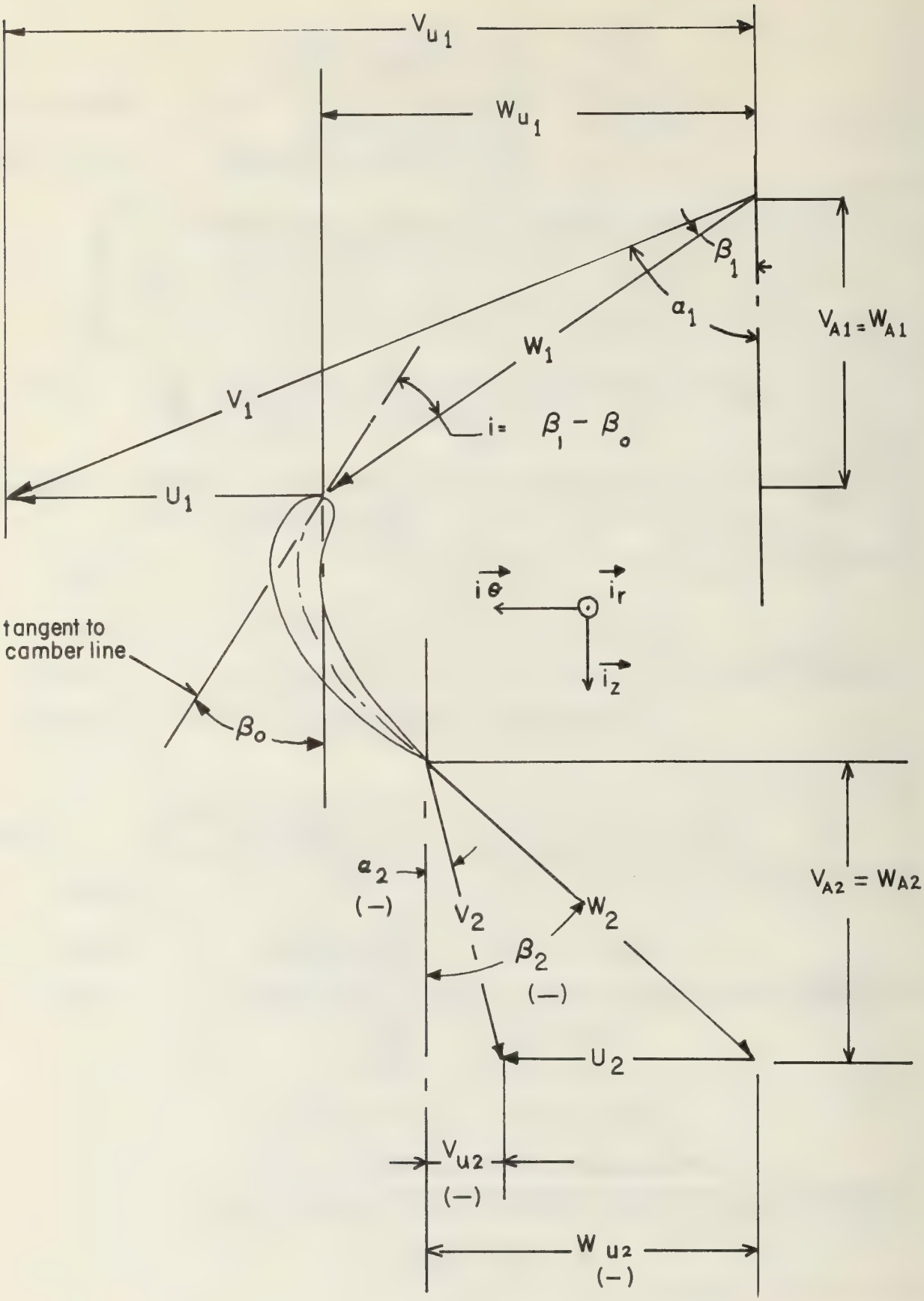
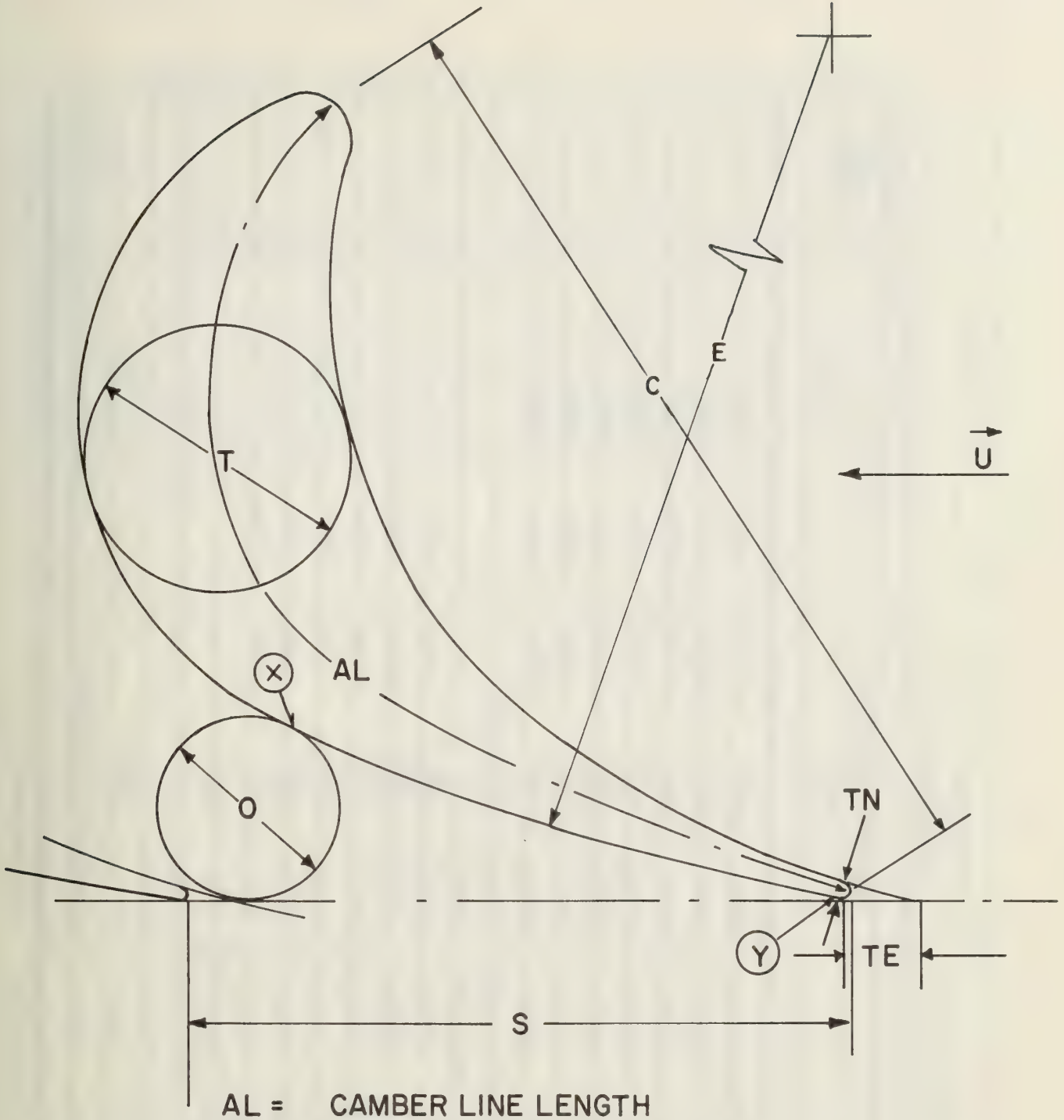


Fig.5 Velocity diagrams



AL = CAMBER LINE LENGTH
C = CHORD
O = THROAT DIAMETER
E = CURVATURE RADIUS
S = SPACING
T = MAXIMUM THICKNESS

TE = TRAILING EDGE THICKNESS PROJECTED IN PERIPHERAL DIRECTION

TN = TRAILING EDGE THICKNESS, NORMAL TO FLOW DIRECTION

Fig.6 Blade geomety nomenclature

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PAGE 1 OF 2 | SPECIAL INSTRUCTIONS: FIXED IMPUT DATA

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TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (O = ZERO, Ø = ALPHA O; I = ONE, I = ALPHA I; Z = TWO, Z = ALPHA Z)	SERIAL NUMBER
	.06	3	.049 .037 .028 .022 .02 .018 .017 .018	
	.06	4	.051 .04 .030 .024 .02 .021 .020 .022	
	.06	5	.053 .041 .032 .027 .024 .024 .027 .034	
	.06	7	.054 .043 .035 .030 .029 .030 .034 .042	
	.06	8	.056 .045 .039 .037 .039 .042 .048 .056	
	.07	0	.057 .051 .048 .048 .051 .053 .060 .070	
	.07	3	.063 .059 .057 .060 .064 .071 .080 .093	
	.30		.40 .50 .60 .70 .80 .90 1.00	
	40.		50. 60. 65. 70. 75. 80.	
	.14	0	.108 .087 .075 .068 .067 .070 .076	
	.14	2	.112 .092 .080 .075 .076 .081 .088	
	.14	5	.115 .098 .088 .085 .088 .094 .104	
	.14	8	.118 .106 .102 .103 .108 .116 .125	
	.15	6	.131 .119 .115 .121 .128 .140 .152	
	.16	2	.142 .136 .140 .149 .162 .176 .192	
	.30		.40 .50 .60 .70 .80 .90 1.00	
	40.		50. 55. 60. 65. 70.	
	.05	7	0. .0465 .0440 .0428 .0424	
	.04	2	4. .0422 .0420 .0402 .0313 .0000	
	.05	3	0. .0415 .0350 .0330 .0323	

EIGHTY COLUMN FORTRAN CODING SHEET 12ND PGS 5220/1 (11-66)

TABLE I (1)

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CARD PUNCH OPERATOR | DATE COMPLETED | SUBMIT FOR PROCESSING ☐ YES ☐ NO

TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z)	SERIAL NUMBER
	.03	2	3 .0320 .0318 .02935 .02000 .000	
	.04	9	5 .0380 .0316 .02496 .02085	
	.02	8	3 .0280 .0275 .02505 .01433 .000	
	.04	7	5 .0355 .0295 .02667 .02500	
	.02	5	0 .0246 .0244 .02028 .01070 .000	
	.04	4	0 .0335 .0273 .02445 .02225	
	.02	2	5 .0216 .0203 .01688 .00000 .000	
	.04	2	0 .0312 .0222 .02045 .01833	
	.01	8	3 .0170 .0154 .01066 .01000 .000	
	.04	2	0 .0300 .0211 .01881 .01521	
	.01	5	0 .0136 .0104 .00500 -.01500	
	.04	2	0 .0300 .0206 .01555 .01225	
	.01	2	5 .0099 .0073 .00000 -.02000	
	10.	15.	20. 25. 30. 40. 50. 60.	
	40.	50.	60. 70. 80.	
	80.	90.	100. 120. 150. 170.	

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TABLE I (2)

CARD	FORTRAN NAME	FORMAT	DESCRIPTION	COMMENTS
1	IND INZ IWR	I 5 I 5 I 5	PRINT INDEX PRINT INDEX PRINT INDEX	SEE TABLE IV
2	ICØR IAI IAN ICL IINC ICØZ ICØN	I 5 I 5 I 5 I 5 I 5 I 5 I 5	LOSS INDEX LOSS INDEX ANGLE INDEX CLEARANCE INDEX LOSS INDEX LOSS INDEX CONTINUITY INDEX	SEE TABLE V
3	VIS2 VIS3 CP EMME GAM	E 12.3 E 12.3 F 10.4 F 10.4 F 10.4	VISCOSITY AT STATION 1 VISCOSITY AT STATION 2 SPECIFIC HEAT AT P=CONST MOLECULAR MASS ISOENTROPIC EXPONENT	(LB/SEC-FT) (LB/SEC-FT) (BTU/LB-DEG. F)
4	TIPC ZS ZR	F 8.4 F 8.4 F 8.4	ROTOR TIP CLEARANCE STATOR NUMBER OF BLADES ROTOR NUMBER OF BLADES	(INCHES)
5	CV CK	F 8.4 F 8.4	AXIAL DISTANCE BETWEEN STATIONS CURVATURE FACTOR	SEE EQ. (16) AND (17) SEE EQ. (16)
7	STALI (I), I=1,10	10F 5.2	ROTOR STALL ANGLES AT 10 RADII EQUALLY SPACED FROM HUB TO TIP	DEFINED BY AINLEY METHOD [6]
6	BETAØ(I) I=1,5,2	3F 8.4	ROTOR BLADE ANGLES, AT HUB, MEAN AND TIP SECTIONS	DEFINED BY THE TANGENT CAMBER LINE SEE FIG. 6

TABLE II (1)

CARD	FORTRAN NAME	FORMAT	DESCRIPTION	COMMENTS
8	A1 (I), I=1,5	5F8.4	STATOR BLADE OPENINGS AT FIRST FIVE RADII OF CARD 7	(INCHES)
9	A1((I), I=6,10	5F8.4	SAME AS CARD 8, AT SECOND FIVE RADII OF CARD 7	(INCHES)
10	A2 (I), I=1,5	5F8.4	SAME AS CARD 8, FOR ROTOR BLADE	(INCHES)
11	A2 (I), I=6,10	5F8.4	SAME AS CARD 9, FOR ROTOR BLADE	(INCHES)
12	AL ALI AL$\emptyset$	F8.5 F8.5 F8.5	STATOR BLADE CAMBER LINE LENGTH, MEAN SECTION STATOR BLADE CAMBER LINE LENGTH, HUB SECTION STATOR BLADE CAMBER LINE LENGTH, TIP SECTION	SEE FIG. 6 (INCHES)
13	C CI C$\emptyset$	F8.5 F8.5 F8.5	STATOR BLADE CHORD, MEAN SECTION STATOR BLADE CHORD, HUB SECTION STATOR BLADE CHORD, TIP SECTION	SEE FIG. 6 (INCHES)
14	E EI E$\emptyset$	F8.5 F8.5 F8.5	STATOR BLADE CURVATURE, MEAN SECTION STATOR BLADE CURVATURE, HUB SECTION STATOR BLADE CURVATURE, TIP SECTION	SEE FIG. 6 (INCHES)
15	T TI T$\emptyset$	F8.5 F8.5 F8.5	STATOR BLADE MAXIMUM THICKNESS, MEAN SECTION STATOR BLADE MAXIMUM THICKNESS, HUB SECTION STATOR BLADE MAXIMUM THICKNESS, TIP SECTION	SEE FIG. 6 (INCHES)
16	TE TEI TE$\emptyset$	F8.5 F8.5 F8.5	STATOR BLADE T.E. PROJECTED THICKNESS, MEAN SECTION STATOR BLADE T.E. PROJECTED THICKNESS, HUB SECTION STATOR BLADE T.E. PROJECTED THICKNESS, TIP SECTION	SEE FIG. 6 (INCHES)
17	TN TNI TN$\emptyset$	F8.5 F8.5 F8.5	STATOR BLADE T.E. NORMAL THICKNESS, MEAN SECTION STATOR BLADE T.E. NORMAL THICKNESS, HUB SECTION STATOR BLADE T.E. NORMAL THICKNESS, TIP SECTION	SEE FIG. 6 (INCHES)

TABLE II (2)

CARD	FORTRAN NAME	FORMAT	DESCRIPTION	COMMENTS
18-23		F8.5	SAME OF CARDS 12-17, FOR ROTOR BLADE	(INCHES)
24	RC (1) RC (5)	F8.4 F8.4	HUB RADIUS AT STATION 0 TIP RADIUS AT STATION 0	(INCHES)
25	RS (1) RS (5)	F8.4 F8.4	HUB RADIUS AT STATION 1 HUB RADIUS AT STATION 1	(INCHES)
26	RR (1) RR (5)	F8.4 F8.4	HUB RADIUS AT STATION 2 TIP RADIUS AT STATION 2	(INCHES) WITHOUT TIP CLEARANCE
27	TØL1 TØL2 TØL3 TØL4	F8.4 F8.4 F8.4 F8.4	REL. TOLERANCE IN OVERALL CONTINUITY REL. TOLERANCE IN STREAMLINE CONTINUITY REL. TOLERANCE IN PRESSURE RATIO REL. TOLERANCE IN VELOCITY DISTRIBUTION	
28	NSETS	I5	NUMBER OF SETS OF OPERATING CONDITIONS FOR WHICH SOLUTIONS HAVE TO BE FOUND	
29 + (28+NSETS)	AMC AMS PTØ TTØ AMR RPM PR VA1(3) VA2(3)	F8.4 F8.4 F8.4 F8.4 F8.4 F8.4 F8.4 F8.4 F8.4	MACH NUMBER AT STATION 0 MACH NUMBER AT STATION 1 TOTAL PRESSURE AT STATION 0 TOTAL TEMPERATURE AT STATION 0 MACH NUMBER AT STATION 2 SPEED OF REVOLUTION TOTAL-STATIC PRESSURE RATIO AXIAL VELOCITY AT MEAN STR. AT STATION 1 AXIAL VELOCITY AT MEAN STR. AT STATION 2	APPROXIMATE VALUE APPROXIMATE VALUE (PSI) ASSUMED TO BE CONSTANT (^{o}R) ASSUMED TO BE CONSTANT APPROXIMATE VALUE (REVOLUTION/MINUTE) MASS AVERAGED QUANTITY APPROXIMATE VALUE APPROXIMATE VALUE

TABLE II (3)

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CARD PUNCH OPERATOR | DATE COMPLETED | SUBMIT FOR PROCESSING ☐ YES ☐ NO

TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, ø = ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z)	SERIAL NUMBER
	0		0 0	
	4		0 2 0 1 2	
	1		3.0E-04 .120E-04 .224 2.8.97 0 1.40	
	.03	0	40. 76.	
	2.	5	5.	
	5	0	.4 3. 30.	
	1.0		1.3 1.6 1.8 12.0 13.0 14.0 15.0 17.0 18.5	
	0.52	5	2.0.5855 0.6455 9.0.7024 -7665	
	0.82	6	8.0.8881 0.9439 4.1.0198 .0722	
	0.62	5	.0.6411 0.6557 0.6737 0.6884	
	0.703		.0.7177 0.7399 0.7401 0.7488	
	2.96		2.82 3.34	
	2.83		2.54 3.15	
	20.		20. 20.	
	0.33		0.33 0.36	
	0.063		0.0744 0.0556	
	0.025		0.0255 0.025	
	2.47		2.46 2.50	
	2.16		2.13 2.16	
	8.0		5.30 8.0	

PROGRAMMER: E. MACCHI | PROGRAM: AXIAL TURBINES | DATE: AUG. 1970

PAGE 2 OF 2 | SPECIAL INSTRUCTIONS: VARIABLE IMPUT DATA

CARD PUNCH OPERATOR | DATE COMPLETED | SUBMIT FOR PROCESSING ☐ YES ☐ NO

TYPE	STATEMENT NO.	CONT.	FORTRAN STATEMENT (0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z)	SERIAL NUMBER
	0.38		0 .384 0. 25	
	0.0435		0 .046 0. 03814	
	0.030		0 .030 0. 030	
	10. 5		15.0	
	10. 5		15.0	
	10. 5		15.0	
	0. 0001		0.001 0.001 0. 01	
	1			
	.215		0 .9 44. 5500.0 0.7 3262.0 1 .50 330 .330.	

PRINT INDEX	POSSIBLE VALUES	SPECIFICATIONS
IND	1	Intermediate results are printed in subroutines CHAN, STATØR, RØTØR2, FLØWR, SLINE
	≠ 1	No intermediate prints.
INZ	1	Solutions are printed for all calculated pressure ratios
	≠ 1	Solutions are printed only for specified pressure ratios
IWR	1	Intermediate results in loss coefficients subroutines are printed
	≠ 1	No intermediate prints

TABLE IV

CORRELATION INDEX	POSSIBLE VALUES	SPECIFICATIONS
ICØR	1	A&M [6] or D&C [7] loss correlation method is adopted, depending on IAI value.
	2	Balje [8] loss correlation method is adopted.
	3	L&C [9] loss correlation method is adopted.
	4	Traupel [10] loss correlation method is adopted.
IAI	0	If ICOR=1, A&M [6] loss correlation method is adopted.
	1	If ICOR=1, D&C [7] loss correlation method is adopted.
IAN	1	A&M [6] flow angles correlation is adopted.
	2	Traupel [10] flow angles correlation is adopted.
ICL	0	Rotor is not shrouded.
	1	Rotor is shrouded.

TABLE V (1)

CORRELATION INDEX	POSSIBLE VALUES	SPECIFICATIONS
IINC	0	Loss coefficients are function of flow angles
	1	Loss coefficients are function of blade inlet angles, for negative incidence
ICØZ	1	Loss coefficient $\zeta = \zeta_o$ (see eq. (42))
	6	Loss coefficient $\zeta = \zeta$ (Y, pressure ratio) (see eq. (41))
	8	Loss coefficient $\zeta = \zeta_{M=0.8}$ (see eq. (43))
ICØN	1	Loss coefficient in continuity equation $\zeta^* = .5\ \zeta_{TOT}$
	2	Loss coefficient in continuity equation $\zeta^* = \zeta_{PROF}$
	3	Loss coefficient in continuity equation $\zeta^* = \zeta_{TOT}$

TABLE V (2)

TABLE VI

EXAMPLE OF NORMAL OUTPUT DATA

R1	A1	R2	A2
10.500	0.5252	10.500	0.6250
11.000	0.5855	11.000	0.6410
11.500	0.6459	11.500	0.6570
12.000	0.7002	12.000	0.6730
12.500	0.7665	12.500	0.6880
13.000	0.8268	13.000	0.7030
13.500	0.8881	13.500	0.7170
14.000	0.9494	14.000	0.7390
14.500	1.0108	14.500	0.7400
15.000	1.0722	15.000	0.7480

NUMBER OF STATOR BLADES = 40.
NUMBER OF ROTOR BLADES = 76.
ROTOR TIP CLEARANCE = 0.0300
AXIAL DISTANCE L = 2.50
CURVATURE FACTOR K = 5.00

BLADING GEOMETRY

	C	E	T	TE	TN	AL	R
STATOR	2.5400	20.0000	0.3300	0.0740	0.0250	2.8200	10.5000
	2.8300	20.0000	0.3300	0.0631	0.0250	2.9600	12.7500
	3.1500	20.0000	0.3600	0.0560	0.0250	3.3400	15.0000
ROTOR	2.1300	5.3000	0.3840	0.0460	0.0300	2.4600	10.5000
	2.1600	8.0000	0.3800	0.0435	0.0300	2.4700	12.7500
	2.1600	8.0000	0.2500	0.0384	0.0300	2.5000	15.0000

ALL DIMENSIONS INDICATED IN THIS TABLE ARE IN INCHES

CORRELATION SYSTEM
ICOR = 4
IAI = 0
IAN = 2
ICOZ = 1
IINC = 1
ICL = 0
ICON = 2

GAS PROPERTIES	CP (BTU/LB F)	MOLECULAR MASS	GAMMA	VISCOSITY (1) (LBM /SEC FT)	VISCOSITY (2) (LBM /SEC FT)
	0.240	28.970	1.400	0.130E-04	0.120E-04

SET NUMBER	PAGE NUMBER	RPM	TOTAL/STATIC PRESSURE RATIO	INLET TOTAL PRESSURE (PSI)	INLET TOTAL TEMPERATURE (DEG. R)
1	1	3262.0	1.500	44.000	550.00

STATOR EXIT SOLUTION

STREAM LINE	RADIAL POSITION (IN)	X=R/RM	RADIAL SHIFT (IN)	BLADE OPENING (IN)	Y=VA/VAM	BLADE EFFICIENCY	LOSS COEFFICIENT	ZETA* CONTINUITY	FLOW RATE FRACTION
1	10.500	0.802	0.0	0.5240	0.9172	0.9203	0.0797	0.0366	0.0
2	11.917	0.911	-0.1301	0.6920	0.9642	0.9215	0.0785	0.0352	0.2491
3	13.085	1.000	-0.1379	0.8286	1.0000	0.9224	0.0776	0.0342	0.5001
4	14.095	1.077	-0.0838	0.9569	1.0200	0.9229	0.0771	0.0331	0.7501
5	15.000	1.146	0.0	1.0733	1.0296	0.9233	0.0767	0.0324	1.0000

	ABSOLUTE VELOCITY (FPS)				RELATIVE VELOCITY (FPS)				
STREAM LINE	AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	WHEEL VELOCITY
1	296.13	0.0	876.67	925.33	296.13	0.0	577.77	649.24	298.90
2	311.30	3.73	780.22	840.04	311.30	3.73	440.97	539.80	339.24
3	322.87	4.06	721.50	790.46	322.87	4.06	349.02	475.48	372.48
4	329.32	3.23	682.88	758.14	329.32	3.23	281.65	433.34	401.23
5	332.41	0.0	646.46	726.91	332.41	0.0	219.46	398.32	427.00

	MACH NUMBER		FLOW ANGLE (DEG)		TEMPERATURE (DEG. R)		PRESSURE (PSI)		PRESSURE RATIO	
STREAM LINE	ABSOLUTE	RELATIVE	ABSOLUTE	RELATIVE	TOTAL	STATIC	TOTAL	STATIC	TOT/TOT	TOT/STA
1	0.86	0.61	71.34	62.87	550.00	478.75	42.048	25.874	1.0464	1.7006
2	0.77	0.50	68.25	54.78	550.00	491.28	42.453	28.595	1.0364	1.5387
3	0.72	0.43	65.90	47.23	550.00	498.01	42.662	30.137	1.0314	1.4600
4	0.69	0.39	64.26	40.54	550.00	502.17	42.786	31.118	1.0284	1.4140
5	0.66	0.36	62.79	33.44	550.00	506.03	42.898	32.047	1.0257	1.3730

SET NUMBER	PAGE NUMBER	RPM	TOTAL/STATIC PRESSURE RATIO	INLET TOTAL PRESSURE (PSI)	INLET TOTAL TEMPERATURE (DEG. R)
1	2	3262.0	1.500	44.000	550.00

ROTOR EXIT SOLUTION

STREAM LINE	RADIAL POSITION	X=R/RM	RADIAL SHIFT	BLADE OPENING	Y=VA/VAM	BLADE EFFICIENCY	LOSS COEFFICIENT	ZETA* CONTINUITY	FLOW RATE FRACTION
1	10.500	0.811	0.0	0.6251	1.0222	0.8277	0.1723	0.0879	0.0
2	11.785	0.911	-0.0599	0.6662	1.0312	0.8562	0.1438	0.0641	0.2505
3	12.940	1.000	-0.0628	0.7006	1.0000	0.8729	0.1271	0.0502	0.5004
4	14.017	1.083	-0.0490	0.7274	0.9749	0.8846	0.1154	0.0419	0.7505
5	15.000	1.159	0.0	0.7479	0.9680	0.8924	0.1076	0.0363	1.0000

	ABSOLUTE VELOCITY (FPS)				RELATIVE VELOCITY (FPS)				
STREAM LINE	AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	AXIAL COMPONENT	RADIAL COMPONENT	TANGENTIAL COMPONENT	OVERALL VELOCITY	WHEEL VELOCITY
1	328.25	0.0	-0.30	328.25	328.25	0.0	-299.20	444.15	298.90
2	331.14	3.97	-0.46	331.16	331.14	3.97	-335.93	471.72	335.47
3	321.13	4.04	10.51	321.33	321.13	4.04	-357.83	480.32	368.34
4	313.07	3.07	22.43	313.88	313.07	3.07	-376.59	489.74	399.02
5	310.86	0.0	25.66	311.92	310.86	0.0	-401.34	507.65	427.00

	MACH NUMBER		FLOW ANGLE (DEG)		TEMPERATURE (DEG. R)		PRESSURE (PSI)		PRESSURE RATIO	
STREAM LINE	ABSOLUTE	RELATIVE	ABSOLUTE	RELATIVE	TOTAL	STATIC	TOTAL	STATIC	TOT/TOT	TOT/STA
1	0.30	0.41	-0.05	-42.35	506.38	497.41	30.736	28.873	1.4315	1.5239
2	0.30	0.43	-0.08	-45.42	505.92	496.90	31.002	29.109	1.4193	1.5116
3	0.29	0.44	1.87	-48.10	505.92	497.45	31.223	29.432	1.4092	1.4950
4	0.29	0.45	4.10	-50.27	505.89	497.77	31.352	29.626	1.4034	1.4852
5	0.29	0.46	4.72	-52.24	505.88	497.79	31.437	29.711	1.3996	1.4810

STREAM LINE	EQUIVALENT TEMPERATURE (DEG. R)	EQUIVALENT INLET PRESSURE (PSI)	EQUIV/STATIC PRESSURE RATIO	BLADE INLET ANGLE (DEG)	BLADE STALL ANGLE (DEG)	INCIDENCE ANGLE (DEG)
1	513.82	33.14	1.148	50.4	11.0	12.4
2	515.41	33.82	1.162	47.3	11.8	7.5
3	516.69	34.28	1.165	43.0	13.0	4.3
4	517.73	34.63	1.169	38.0	15.2	2.5
5	519.23	35.07	1.180	32.6	18.5	0.8

SET NUMBER	PAGE NUMBER	RPM	TOTAL/STATIC PRESSURE RATIO	INLET TOTAL PRESSURE (PSI)	INLET TOTAL TEMPERATURE (DEG. R)
1	3	3262.0	1.500	44.000	550.00

OVERALL TURBINE CHARACTERISTICS

STREAM LINE	PRESSURE RATIO TOT/STA	PRESSURE RATIO TOT/TOT	EFFICIENCY TOT/STA	EFFICIENCY TOT/TOT	HEAD COEFFICIENT	BLADE/JET SPEED RATIO	THEORETICAL DEGREE OF REACTION
1	1.5239	1.4315	0.6994	0.8142	8.3899	0.3452	-0.2412
2	1.5116	1.4193	0.7197	0.8418	6.3945	0.3955	-0.0405
3	1.4950	1.4092	0.7384	0.8585	5.1708	0.4398	0.0558
4	1.4852	1.4034	0.7505	0.8689	4.3874	0.4774	0.1182
5	1.4810	1.3996	0.7558	0.8757	3.8475	0.5098	0.1842

MASS AVERAGED QUANTITIES

HORSE POWER	=	1954.03	(HP)
MOMENT	=	3146.15	(FT-LB)
FLOW RATE	=	130.69	(LB/SEC)
REFERRED RPM	=	3166.91	
REFERRED HORSE POWER	=	633.79	(HP)
REFERRED MOMENT	=	1051.10	(FT-LB)
REFERRED FLOW RATE	=	44.97	(LB/SEC)
TOTAL/STATIC EFFICIENCY	=	0.7341	
TOTAL/TOTAL EFFICIENCY	=	0.8535	
TOTAL/STATIC PRESSURE RATIO	=	1.4985	
TOTAL/TOTAL PRESSURE RATIO	=	1.4119	
HEAD COEFFICIENT	=	5.5178	
BLADE/JET SPEED RATIO	=	0.4257	
THECRETICAL DEGREE OF REACTION	=	0.0262	
MACH NUMBER AT STATION 0	=	0.2162	

APPENDIX

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C
C      ANGLES CORRELATION INDECES
C
C      IAN=1 AINLEY   METHOD
C      IAN=2 TRAUPEL  METHOD
C
C      LOSSES CORRELATION INDECES
C
C      ICOR=1  AYNLEY (IAI=0)  OR DUNHAM (IAI=1)
C      ICOR=2  BALJE           METHOD
C      ICOR=3  LENHERR   CARTER  METHOD
C      ICOR=4  TRAUPEL    METHOD
C      ICOZ=1  ZETA IS CONSTANT, EQUAL TO THE VALUE AT MACH=0
C      ICOZ=6  Y IS CONSTANT, ZETA IS PRESSURE RATIO DEPENDENT
C      ICOZ=8  ZETA IS CONSTANT,EQUAL TO THE VALUE AT MACH=0.8
C      IINC=0  LOSSES ARE FUNCTION OF FLOW ANGLES
C      IINC=1  LOSSES ARE FUNCTION OF BLADE ANGLES,FOR NEGATIVE INCIDENCE
C      (FOR METHOD 4)
C
C      ICL=0  NOT SHROUDED ROTOR
C      ICL=1  SHORUDED ROTOR
C
C      CONTINUITY EQUATION CORRELATION
C
C      ICON=1   ZETAP=.5*(ZETA TOT)
C      ICON=2   ZETAP=(ZETAP)
C      ICON=3   ZETAP=ZETA
C
C
C      PRINT  INDECES
C
C      IND=0   NO INTERMEDIATE WRITING
C      IND=1      INTERMEDIATE WRITING
C
C      INZ=0   NO INTERMEDIATE WRITING FOR       DIFFERENT PRESSURE RATIOS
C      INZ=1      INTERMEDIATE WRITING FOR  DIFFERENT PRESSURE RATIOS
C      IWR=1 INTERMEDIATE PRINTS IN  LOSS  SUBROUTINES
C
C
0001            DIMENSION ETAT(5), BETAT(5),TTIS(5)
0002           0DIMENSION ALFAM(10),BETAM(10),RS(10),RR(10),ZETAR(10),ZETAPR(10),
               1CALF(10),DBET(10),AS(10),AR(10),X1(10),X2(10),ALFA1(10),BETA2(10),
               2T1(10),P1(10),V1(10),VA1(10),SI1(10),SI2(10),YS(10),S1(10),
               3DSDX1(10),VU1(10),PRAT1(10),ZETAPS(10),WI1(10),VA2(10),WPER1(10),
               4U(10),BETA1(10),HE(10),TTE(10),PTE(10),W1(10),WU1(10),DHEDX(10),
               5DSDX2(10),WU2(10),W2(10),VU2(10),V2(10),YR(10),RI1(10),RI2(10),
               6RI3(10),RI4(10),RI(10),SR1(10),SR2(10),YOLD(10),AA(10),SR(10),
               7P2(10),T2(10),PRAT2(10),WPER2(10),DWDX(10),U2(10),TIIS(10),
               8 T2IS(10),PRAT3(10),SS(10),ALFA2(10)
0003           0DIMENSION DELH(10),TT2(10),PT2(10),PT1(10),T2S(10),
               1ETAI(10),ETAS(10),PSIR(10),RSTAR(10),AKIS(10),ETAR(10),
               2ALFA(10),BETA(10),AMS1(10),RC(10),DELR(10),WPERO(10),ZETAS(10),
               3ZETAR1(20),ZETAR3(20),ZETAR5(20),BETAO(10),STALI(10)
0004            DIMENSION R1(20),A1(20),B1(20),T10(20),ST1(20),IRR(20),R2(20),A2(2
               10),B2(20),B6(20),RINC(20),DR(10),BETO(10),STALII(10),RINCI(10),AMR
               22(10),ALFA22(10),BETA22(10),ALFA11(10),BETA11(10),ZETAI(10),AREA1(
               310),AREA2(10),VR1(10),WR2(10)
0005            DIMENSION AMW1(10),PRAT1T(10),DR1(10),BETET(10) ,AMV2(10)
0006            COMMON /ABA/ BA17,BLEX
0007            COMMON /CUR/ COSL(10)
0008            COMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0009            COMMON /TR5/ TRA5
0010            COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0011            COMMON /COZ/ ICCR,ICOZ,IINC,IAI,ICL,IAN,ICON
0012             COMMON /MAC/ IN
0013            COMMON /IWI/ IND,INZ,IWR
0014            COMMON /AUS/ XCL
0015            COMMON /CSS/ CJ,G,C1
0016            COMMON /ALI/  ALFAI,V1,TTO,RPM,RS,SI,TNI,H,D,CI,T1,P1,TO,TEI,ALI,
               1BESP,XX,ANG2O,AMS1,S,TN,C,TE,AL,SO,TNO,CO,TEO,U ,D1I,D1O,D2I,D2O,
               2ANG21,ALFAX,TI,T,PTO,ALO,AMC
0017            COMMON /AL2/  BETA2,BETAI,BETAO,W2,TTE,U2,SIR,TNIR,HR,DZ,CIR,TIPC,
               1SZ,TNR,CP,SOR,TNOR,COR,ALIR,ALR,ALOR,P2,WU2,W1   ,TEIR,TER,TEOR,
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     2D1IR,D1OR,BETAZ,BETAI,ANM,TIR,TR,TOR,STALI,PTE,RS1,RS3,RS5,T2
0018  TRA5=1.
0019    XX=1.25
0020  BLEX=0.15
0021  IF(ICL.EQ.0)XCL=1.35
0022  IF(ICL.EQ.1)XCL=.7
0023   CALL COEFF1
0024   CALL COEFF2
0025  CALL TRAUP1
0026 3301 FORMAT(3F8.5)
0027    3 FORMAT(5F8.4)
0028    1 FORMAT(5F8.4)
0029  784 FORMAT(10F5.2)
0030  783  FORMAT(2F8.4)
0031 3340   FORMAT(2E12.3,3F10.4)
0032 3403   FORMAT(//3E20.4)
0033    2 FORMAT(3F8.4)
0034      READ(5,4) IND,INZ,IWR
0035      READ(5,4) ICOR,IAI,IAN,ICL,IINC,ICOZ,ICON
0036      READ(5,3340)VIS2,VIS3,CP,EMME,GAM
          C     NUMERICAL CONSTANTS
0037      G=32.174
0038      CJ=778.16
0039      EXP1=GAM/(GAM-1.)
0040      EXP2=1./EXP1
0041      ERRE=1545.43/EMME
0042       BESP=(1.+( GAM-1.)/2.*0.64)**(-GAM/(GAM-1.))
0043      READ(5,2)TIPC,ZS,ZR
0044      READ (5,783) CV,CK
0045      READ (5,2) (BETAO(I),I=1,5,2)
0046      DO 611 I=1,5,2
0047  611      BETAO(I)= BETAO(I)*3.14159/180.
0048      READ(5,784)(STALI(I),I=1,10)
0049      READ(5,3)(A1(I),I=1,5)
0050      READ(5,3)(A1(I),I=6,10)
0051      READ(5,3)(A2(I),I=1,5)
0052      READ(5,3)(A2(I),I=6,10)
0053      READ(5,3301) AL,ALI,ALO
0054      READ(5,3301)C,CI,CO
0055      READ(5,3301)E,EI,EO
0056      READ(5,3301)T,TI,TO
0057      READ(5,3301)TE,TEI,TEO
0058      READ(5,3301) TN,TNI,TNO
0059      READ(5,3301)ALR,ALIR,ALOR
0060      READ(5,3301) CR,CIR,COR
0061      READ(5,3301) ER,EIR,EOR
0062      READ(5,3301)TR,TIR,TOR
0063      READ(5,3301) TER,TEIR,TEOR
0064      READ(5,3301) TNR,TNIR,TNOR
          C
0065      READ(5,1) RC(1),RC(5)
0066      READ(5,1) RS(1),RS(5)
0067      READ(5,1) RR(1),RR(5)
0068      READ(5,3)TOL1,TOL2,TOL3,TOL4
0069 3341 FORMAT( 4E15.5)
0070      RC(2)=SQRT(RC(5)*RC(5)/4.+3./4.*RC(1)*RC(1))
0071      RC(3)=SQRT(RC(5)*RC(5)/2.+RC(1)*RC(1)/2.)
0072      RC(4)=SQRT(3./4.*RC(5)*RC(5)+RC(1)*RC(1)/4.)
0073      RS(2)=SQRT(RS(5)*RS(5)/4.    +RS(1)*RS(1)/4.*3.)
0074      RS(3)=(RS(1) +RS(5) )/2.
0075      RS(4)=SQRT(RS(5)*RS(5)/4.*3.+RS(1)*RS(1)/4.)
0076      RR(2)=SQRT(RR(5)*RR(5)/4.+3./4.*RR(1)*RR(1))
0077      RR(3)=(RR(1) +RR(5) )/2.
0078      RR(4)=SQRT(RR(5)*RR(5)*3./4.+   RR(1)*RR(1)/4.)
0079      DO 3300 I=1,10
0080      A =I
0081      R1(I)=RS(1)+(A-1.)/9. *(RS(5)-RS(1))
0082 3300 R2(I)=RR(1)+(A-1.)/9.*(RR(5)-RR(1))
0083        OI= A1(1)
0084       OO= A1(10)
0085      OIR= A2(1)
0086      OOR= A2(10)
0087       DO 3711 I=1,10
```

```
0088                IF(RS(3).LE.R1(I)) GOTO 3712
0089          3711   CONTINUE
0090          3712  CONTINUE
0091                I=I-1
0092                 O = A1(I)+ (A1(I+1)-A1(I))*(RS(3)-R1(I))/(R1(I+1)-R1(I))
0093                 DO 3713 I=1,10
0094                 IF(RR(3).LE.R2(I)) GOTO 3714
0095          3713   CONTINUE
0096          3714    CONTINUE
0097                I=I-1
0098                 OR=  A2(I)+ (A2(I+1)-A2(I))*(RR(3)-R2(I))/(R2(I+1)-R2(I))
0099               H=RS(5)-RS(1)
0100               D=2.*RS(3)
0101               S=2.*3.1416*RS(3)/ZS
0102               SI=2.*3.1415*RS(1)/ZS
0103               SO=2.*3.1416*RS(5)/ZS
0104               SZ=2.*3.1416*RR(3)/ZR
0105               SIR=2.*3.1416*RS(1)/ZR
0106               SOR=2.*3.1416*RS(5)/ZR
0107               DZ=2.*RR(3)
0108               HR=RR(5)-RR(1)
0109               ANG1=0.
                C
                CC      AINLEY METHOD , STATOR EXIT ANGLES AT DIFFERENT  MACH NUMBERS
                C
0110                CL= TIPC
0111               CALL ANGAIN(ANG1,ALFAM(1),S,C,O,E,TE,0.5,0.,H,D,IWR,ANG21)
0112               CALL ANGAIN(ANG1,ALFAM(2),S,C,O,E,TE,0.7,0.,H,D,IWR,ANG21)
0113               CALL ANGAIN(ANG1,ALFAM(3),S,C,O,E,TE,0.75,0.,H,D,IWR,ANG21)
0114               CALL ANGAIN(ANG1,ALFAM(4),S,C,O,E,TE,0.80,0.,H,D,IWR,ANG21)
0115               CALL ANGAIN(ANG1,ALFAM(5),S,C,O,E,TE,1.0, 0.,H,D,IWR,ANG21)
0116               ALFAX=ALFAM(1)
0117               DO 3303 I=1,5
0118          3303 ALFAM(I)=-ALFAM(I)
0119               D1I=2.*RC(1)
0120               D1O=2.*RC(5)
0121               D2I=2.*RS(1)
0122               D2O=2.*RS(5)
0123               CALL ANGAIN(ANG1,ANG2I,SI,CI,OI,EI,TEI,0.5,0.,H,D,IWR,ANG21)
0124               CALL ANGAIN(ANG1,ANG2O,SO,CO,OO,EO,TEO,0.5,0.,H,D,IWR,ANG21)
0125               DALF(1)=-ANG2I-ALFAM(1)
0126               DALF(3)=0.
0127               DALF(5)=-ANG2O-ALFAM(1)
                C
                CC      ROTOR EXIT ANGLES
                C
0128               D1IR=2.*RR(1)
0129               D1OR=2.*RR(5)
0130               ANG1= BETAO(3)
0131               CALL ANGAIN(ANG1,BETAM(1),SZ,CR,OR,ER,TER,0.5,CL,HR,DZ,IWR,ANM)
0132               CALL ANGAIN(ANG1,BETAM(2),SZ,CR,OR,ER,TER,0.7,CL,HR,DZ,IWR,ANG21)
0133               CALL ANGAIN(ANG1,BETAM(3),SZ,CR,OR,ER,TER,0.75,CL,HR,DZ,IWR,ANG21)
0134               CALL ANGAIN(ANG1,BETAM(4),SZ,CR,OR,ER,TER,0.80,CL,HR,DZ,IWR,ANG21)
0135               CALL ANGAIN(ANG1,BETAM(5),SZ,CR,OR,ER,TER,1.00,CL,HR,DZ,IWR,ANG21)
0136                 ANG1= BETAO(1)
0137               CALL ANGAIN(ANG1,BETAI,SIR,CIR,OIR,EIR,TEIR,0.5,0.,HR,DZ,IWR,AN)
0138                 ANG1= BETAO(5)
0139               CALL ANGAIN(ANG1,BETAZ,SOR,COR,OOR,EOR,TEOR,0.5,0.,HR,DZ,IWR,AN)
0140               DBET(1)=BETAI-BETAM(1)
0141               DBET(3)=0.
0142               CL=TIPC
0143                ANG1= BETAO(5)
0144               CALL ANGAIN(ANG1,BETAC,SOR,COR,OOR,EOR,TEOR,0.5,CL,HR,DZ,IWR,AN)
0145                 ANG1=0.
0146               DBET(5)=BETAC-BETAM(1)
0147               IF(IAN.EQ.1) GOTO 3377
                C
                CC      ANGLES COMPUTATION  WITH TRAUPEL METHOD
                C
0148               DO 3370 I =1,5
0149          3370 ALFAM(I)=+ANGTRA(TN,S,O)
0150               ANG2I=+ANGTRA(TNI,SI,OI)
0151               ANG2O=+ANGTRA(TNO,SO,OO)
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0152                DALF(1)=       -ALFAM(1)+ANG2I
0153                DALF(3)=0.
0154                DALF(5)=       -ALFAM(1)+ANG2O
0155                DO 3371 I=1,5
0156             3371  BETAM(I)=- ANGTRA(TNR, SZ, OR)
0157                BETAI = -ANGTRA(TNIR,SIR,OIR)
0158                DBET(1)=-BETAM(1)+BETAI
0159                DBET(3)=0.
0160                BETAZ = -ANGTRA(TNOR,SOR,OOR)
0161                DBET(5)=-BETAM(1)+BETAZ
0162             3377 CONTINUE
0163                CALL PARAB (ALFAM,1,2,3,AA1,BA1,CA1,0.5,0.7,0.75)
0164                CALL PARAB(ALFAM,3,4,5,AA2,BA2,CA2,0.75,0.8,1.0)
0165                CALL PARAB (BETAM,1,2,3,AB1,BB1,CB1,0.5,0.7,0.75)
0166                CALL PARAB (BETAM,3,4,5,AB2,BB2,CB2,0.75,0.8,1.0)
0167                DO 10 I=1,5
0168                X1(I)=RS(I)/RS(3)
0169             10 X2(I)=RR(I)/RR(3)
0170                RROLD2=RR(2)
0171                RROLD3=RR(3)
0172                RROLD4=RR(4)
0173                RSOLD2=RS(2)
0174                RSOLD3=RS(3)
0175                RSOLD4=RS(4)
0176                RS1=RS(1)
0177                RS3=RS(3)
0178                RS5=RS(5)
0179                RR1=RR(1)
0180                RR3=RR(3)
0181                RR5=RR(5)
0182                CALL CHBFT(R1,A1,10,B1,4,T10,ST1,IRR)
0183                CALL CHBFT(R2,A2,10,B2,4,T10,ST1,IRR)
0184                ASF=B1(1)+B1(2)*RS(3)+B1(3)*RS(3)**2+B1(4)*RS(3)**3+B1(5)*RS(3)**4
0185                ARF=B2(1)+B2(2)*RR(3)+B2(3)*RR(3)**2+B2(4)*RR(3)**3+B2(5)*RR(3)**4
0186                RSF=RS(3)
0187                ASFO=ASF
0188                RSFO=RSF
0189                RRF=RR(3)
0190                RRFO=RRF
0191                ARFO=ARF
0192                XS1=X1(1)
0193                XS3=X1(3)
0194                XS5=X1(5)
0195                XR1=X2(1)
0196                XR3=X2(3)
0197                XR5=X2(5)
0198                DO 3410 I=1,5,2
0199             3410 BETAO(I)=BETAO(I)*180./3.14159
0200                CALL PARAB(BETAO,1,3,5,BR1,BR2,BR3,XS1,XS3,XS5)
0201                CALL CHBFT(R1,STAL1,10,B6,4,T10,ST1,IRR)
                 C
                 CC      INPUT  PRINTS
                 C
0202                WRITE(6,671)
0203              671 FORMAT(1H1,//60X,12HIMPUT PRINTS//40X,50H       R1          A1
                    1          R2          A2   /)
0204                DO 72 I=1,10
0205                WRITE(6,73)R1(I),A1(I),R2(I),A2(I)
0206             73 FORMAT(40X,F10.3,F10.4,10X,F10.3,F10.4)
0207             72 CONTINUE
0208                WRITE(6,74)ZS,ZR,TIPC,CV,CK
0209             74 FORMAT(/45X,25HNUMBER OF STATOR BLADES =,F8.0/45X,25HNUMBER OF ROT
                   1OR  BLADES =,F8.0/45X,25HROTOR TIP CLEARANCE     =,F8.4/45X,25HAXI
                   2AL DISTANCE L       =,F8.2/45X,25HCURVATURE FACTOR K       =,F8.2/
                   3//55X,16HBLADING GEOMETRY/)
0210                WRITE(6,75)
0211             75 FORMAT(//30X,70H       C         E          T         TE          TN
                    1     AL
                     R   /)
0212                WRITE(6,76)CI,EI,TI,TEI,TNI,ALI,RS(1),C,E,T,TE,TN,AL,RS(3),CO,EO,
                   1TC,TEO,TNO,ALO,RS(5)
0213             76 FORMAT(30X,7F10.4/22X,6HSTATOR,2X,7F10.4/30X,7F10.4/)
0214             77    FORMAT(30X,7F10.4/22X,6HROTOR ,2X,7F10.4/30X,7F10.4/)
0215                WRITE(6,77)CIR,EIR,TIR,TEIR,TNIR,ALIR,RR(1),CR,ER,TR,TER,TNR,ALR,
```

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     1RR(3),COR,EOR,TOR,TEOR,TNOR,ALOR,RR(5)
0216       WRITE(6,78)
0217    78 FORMAT(/40X,52HALL DIMENSIONS INDICATED IN THIS TABLE ARE IN INCHE
     1S/)
0218       WRITE(6,79)ICOR,IAI,IAN,ICOZ,IINC,ICL,ICON
0219    79 FORMAT(////,40X,27HCORRELATION SYSTEM   ICOR =,I5/61X,6HIAI  =,I5/
     161X,6HIAN  =,I5/61X,6HICOZ =,I5/,61X,6HIINC =,I5/61X,6HICL  =,I5/6
     21X,6HICON =,I5)
0220       WRITE(6,81)CP,EMME,GAM,VIS2,VIS3
0221    81 FORMAT(//20X, 91HGAS PROPERTIES          CP        MOLECULAR MASS
     1 GAMMA     VISCOSITY (1)    VISCOSITY (2)/38X,10H(BTU/LB F),32X,13
     2H(LBM /SEC FT),4X,13H(LBM /SEC FT)//36X,F9.3,5X,F10.3,9X,F7.3,2E15
     3.3/)
0222     4 FORMAT(8I5)
0223       READ (5,4) NSETS
0224  3404 FORMAT(10F8.3)
0225       DO 400 J=1,NSETS
0226       READ (5,5) AMC,AMS,PTO,TTO,AMR,RPM,PR,VA1(3),VA2(3)
0227     5 FORMAT (9F8.4)
0228       DO 67 I=1,5
0229       U(I)=RPM*3.1415S/30./12.*RS(I)
0230       DR(I)=0.
0231       DELR(I)=0.
0232       ZETAS(I)=.10
0233       ZETAR(I)=.15
0234       ZETAPS(I)=0.05
0235       ZETAPR(I)=0.05
0236       COSL(I)=1.
0237       YS(I)=1.0
0238    67 YR(I)=1.0
0239       N9=0
0240   750 N5=0
0241       N9=N9+1
0242  7750      CONTINUE
0243       IF( N9.GT.10.AND. INZ.GE.1) GO TO 400
0244   290 IF(AMS-0.75) 30,40,50
0245    30 ALFA1(3)=AA1+BA1*AMS+CA1*AMS**2
0246       GO TO 60
0247    40 ALFA1(3)=ALFAM(3)
0248       GO TO 60
0249    50 IF (AMS-1.) 280,270,270
0250   270 ALFA1(3)=ALFAM(5)
0251       GO TO 60
0252   280 ALFA1(3)=AA2+BA2*AMS+CA2*AMS**2
0253    60 IF(AMR-0.75) 70,80,90
0254    70 BETA2(3)=AB1+BB1*AMR+CB1*AMR**2
0255       GO TO 100
0256    80 BETA2(3)=BETAM(3)
0257       GO TO 100
0258    90 BETA2(3)=AB2+BB2*AMR+CB2*AMR**2
0259   100 RS(2)=RSOLD2
0260       RS(3)=RSOLD3
0261       RS(4)=RSOLD4
0262       DO 530 I=1,5
0263   530 X1(I)=RS(I)/RS(3)
0264       ASF=ASFO
0265       RSF=RSFO
0266       FS1=1.0
0267       FS2=1.0
0268       CALL CHAN (TTO,AMC,PTO,RC,WLBM,WCHAN,WPERO)
0269       NS=0
0270   810 DO 801 K=1,15
0271       CALL STATOR(ALFA1,X1,TTO,PTO,AMS,T1,P1,V1,VA1,SI1,SI2,YS,S1,
     1DSDX1,VU1,PRAT1,TIIS,SS,DALF,AA1,BA1,CA1,AA2,BA2,CA2,ALFAM,RSF,
     2DELR,CV,CK,ZETAPS,RS,RS1,RS3,RS5,ZETAS,DR,ZETA1, AMS1,NS,VR1)
0272       CALL ALOS1(ZETAS,ZETAPS)
0273       DO 120 I=1,5
0274       PTE(I)=PTO
0275   120 TTE(I)=TTO
0276       CALL FLOWR(PRAT1,ZETAPS,X1,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ASF,
     1ZR,RSF,1,WCHAN,VA1,WPER1,CODE,WLBM,B1,RS,TIPC,AREA1)
0277        IF(IN.EQ.1) AMC= AMC-0.0001
0278        IF(IN.EQ.1) GOTO 7750
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0279            IF (CODE-20.)801,802,801
0280          801 CONTINUE
0281          802 CALL SLINE (RS,X1,DWDX,WPER1,WPERO,HE,U ,DHEDX,S1,DSDX1,ASF,RSF,
                 1FS1,FS2,CODE,1,B1)
0282              IF (CODE-40.)81C,300,810
0283          300       CONTINUE
0284              FC1=1.
0285              FC2=FC1**2
0286              ARF=ARFO
0287              RRF=RROLD3
0288              RR(2)=RROLD2
0289              RR(3)=RRF
0290              RR(4)=RROLD4
0291              DO 71 I=1,5
0292              AMS1(I)=V1(I)/(SQRT(GAM*ERRE*G*T1(I)))
0293              X2(I)=RR(I)/RR(3)
0294           71 CONTINUE
0295             OCALL ROTOR1(VU1,VA1,RPM,U,BETA1,HE,TTE,PTE,X2,P1,T1,W1,WU1,X1,
                 1RS,ZETAR,ZETAPR,RR,DHEDX,DSDX1,S1,U2,OMEG,BR1,BR2,BR3,FS1,FS2,
                 2 ZETAR   ,B6,RS1,RS3,RS5,BETO,STALII,RINCI,VR1)
0296              CODE=1.
0297               IMACC=0
0298          201     DO 200 K=1,14
0299              CALL ROTOR2 (BETA2,HE,DHEDX,DSDX1,DSDX2,VA2,WU2,W2,VU2,V2,X2,U2,
                 1YR,ZETAR,RI1,RI2,RI3,RI4,RI,SR1,SR2,AA,SR,TTE,PTE,T2,P2,PRAT2,
                 2T2S,INDS,DBET,BETAM,AB1,BB1,CB1,AB2,BB2,CB2,RRF,DELR,CV,CK,DR,RR,
                 3RR1,RR3,RR5,NS,WR2)
0300              CALL ALOS2(ZETAR,ZETAPR)
0301              IF (INDS-1) 310,320,310
0302           320 WRITE (6,36) (AA(I),I=1,5)
0303              WRITE(6,36)((AA(I),ZETAR(I),VA2(I)),I=1,5)
0304            36 FORMAT(35H ENTRCPY INDETERMINATE,PRINT AA 1-5,5E12.4/,25X,10HZETAR
                 1 1-5,5E12.4/25X,10H VA2   1-5,5E12.4/)
0305              IND=1
0306              GO TO 400
0307           310 CALL FLOWR(PRAT2,ZETAPR,X2,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ARF,ZR,
                 1RRF,2,WCHAN,VA2,WPER2,CODE,WLBM,B2,RR,TIPC,AREA2)
0308               IF(IN.EQ.1) AMC= AMC-0.0001
0309               IF(IN.EQ.1) GOTO 7750
0310              IF (CODE-20.) 200,130,200
0311           200 CONTINUE
0312           130 CALL SLINE (RR,X2,DWDX,WPER2,WPERO,HE,U ,DHEDX,S1,DSDX1,
                 1ARF,RRF,FC1,FC2,CODE,2,B2)
0313               IMACC= IMACC+1
0314               IF( IMACC. GE.10) WRITE(6,4322) YR, ZETAR
0315               IF( IMACC. GE.10) GOTO 220
0316          4322   FORMAT( /20H  LOOP IN SLINE ROT//5E10.3)
0317              IF(CODE-40.) 201,220,201
0318          5000    CONTINUE
0319           220 DO 221 I=1,5
0320              DELR(I)=RS(I)-(RC(I)+RR(I))/2.
0321              DR(I)=RC(I)-RR(I)
0322           221  COSL(I)=SQRT(CV*CV/(DR(I)**2+CV*CV))
0323              NS=1
0324           880 DO 881 K=1,15
0325              CALL ALOS1( ZETAS,ZETAPS)
0326              CALL STATOR(ALFA1,X1,TTO,PTO,AMS,T1,P1,V1,VA1,SI1,SI2,YS,S1,
                 1DSDX1,VU1,PRAT1,TIIS,SS,DALF,AA1,BA1,CA1,AA2,BA2,CA2,ALFAM,RSF,
                 2DELR,CV,CK,ZETAPS,RS,RS1,RS3,RS5,ZETAS,DR,ZETA1,  AMS1,NS,VR1)
0327              DO 860 I=1,5
0328              PTE(I)=PTO
0329           860 TTE(I)=TTO
0330              CALL FLOWR(PRAT1,ZETAPS,X1,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ASF,
                 1ZR,RSF,1,WCHAN,VA1,WPER1,CODE,WLBM,B1,RS,TIPC,AREA1)
0331               IF(IN.EQ.1) AMC= AMC-0.0001
0332               IF(IN.EQ.1) GOTO 7750
0333              IF (CODE-20.)881,822,881
0334           881 CONTINUE
0335           822 CALL SLINE (RS,X1,DWDX,WPER1,WPERO,HE,U2,DHEDX,S1,DSDX1,ASF,RSF,
                 1FS1,FS2,CODE,1,B1)
0336               IF (CODE-40.) 880,861 ,880
0337           861 CALL ROTOR1(VU1,VA1,RPM,U,BETA1,HE,TTE,PTE,X2,P1,T1,W1,WU1,X1,
                 1RS,ZETAR,ZETAPR,RR,DHEDX,DSDX1,S1,U2,OMEG,BR1,BR2,BR3,FS1,FS2,
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0339          894 DO 896 K=1,10
0340              CALL ALOS2( ZETAR,ZETAPR)
0341              CALL ROTOR2 (BETA2,HE,DHEDX,DSDX1,DSDX2,VA2,WU2,W2,VU2,V2,X2,U2,
                 1YR,ZETAR,RI1,RI2,RI3,RI4,RI,SR1,SR2,AA,SR,TTE,PTE,T2,P2,PRAT2,
                 2T2S,INDS,DBET,BETAM,AB1,BB1,CB1,AB2,BB2,CB2,RRF,DELR,CV,CK,DR,RR,
                 3RR1,RR3,RR5,NS,WR2)
0342              IF(INDS-1)895,320,895
0343          895 CALL FLOWR(PRAT2,ZETAPR,X2,WI1,PTE,PTO,TTE,TTO,ASF,ZS,RSF,ARF,ZR,
                 1RRF,2,WCHAN,VA2,WPER2,CODE,WLBM,B2,RR,TIPC,AREA2)
0344                IF(IN.EQ.1) AMC= AMC-0.0001
0345                IF(IN.EQ.1) GOTO 7750
0346              IF(CODE-20.)896,897,896
0347          896 CONTINUE
0348          897 CALL SLINE (RR,X2,DWDX,WPER2,WPERO,HE,U2,DHEDX,S1,DSDX1,
                 1ARF,RRF,FC1,FC2,CODE,2,B2)
0349              IF (CODE-40.)894,226,894
0350          226 DO 227 I=1,5
0351          227 PRAT3(I)=PTO/P2(I)
0352              IND=0
0353              PRAT5=(PRAT3(1)+2.*(PRAT3(2)+PRAT3(3)+PRAT3(4))+PRAT3(5))/8.
0354              DIFF=ABS(PR-PRAT5)
0355              TAL=TOL3*PR
0356              IF(TAL  -DIFF)910,920,920
0357          910 N11=0
0358                REC3= AMC
0359                DIFFE=PR-PRAT5
0360              IF(N9.GE.2) AMC=AMC+ DIFFE*(AMC-REC2)/ (REC1-DIFFE)*0.75
0361                REC2= REC3
0362                REC1= DIFFE
0363              IF(N9.LE.1)GOTO 710
0364              IF(INZ.EQ.1) GOTO 223
0365              IF(N9.GT.9) GOTO 223
0366              GOTO 750
0367          920 N11=1
0368              GO TO 223
0369          710 IF(PR-PRAT5)712,712,714
0370          712 AMC= AMC*( 1.- DIFF/PR*0.100)
0371              IF(INZ-1)750,223,223
0372          714 AMC= AMC*( 1.+ DIFF/PR*0.100)
0373              IF(INZ-1)750,223,223
0374          223 CONTINUE
0375          999 FORMAT (1H1)
0376              WRITE(6,999)
0377              WRITE(6,401)
0378          401 FORMAT(///27X,67HSET      PAGE      RPM    TOTAL/STATIC     INLET T
                 1OTAL   INLET TOTAL)
0379              WRITE(6,402)
0380          402 FORMAT(   27X,67HNUMBER  NUMBER            PRESSURE RATIO   PRESSUR
                 1E      TEMPERATURE)
0381              WRITE(6,403)
0382          403 FORMAT(72X, 5H(PSI), 7X,8H(DEG. R)/)
0383              IS=1
0384              WRITE(6,405)J,IS,RPM,PR,PTO,TTO
0385          405 FORMAT(27X,I3,I8,F11.1,F14.3,F14.3,F15.2/)
0386              WRITE(6,404)
0387          404 FORMAT(//57X21H STATOR EXIT SOLUTION///)
0388              WRITE(6,406)
0389          406 FORMAT(1X,109HSTREAM    RADIAL    X=R/RM   RADIAL   BLADE     Y=VA
                 1/VAM      BLADE          LOSS          ZETA*       FLOW RATE)
0390              WRITE(6,407)
0391          407 FORMAT(1X,109H LINE     POSITION            SHIFT   OPENING
                 1      EFFICIENCY   COEFFICIENT   CONTINUITY    FRACTION /)
0392              WRITE(6,411)
0393          411 FORMAT(12X,4H(IN),13X,4H(IN),5X,4H(IN))
0394              DO 408 I=1,5
0395              PRAT1(I)=1./PRAT1(I)
0396              RINC1(I)=RINC1(I)*57.3
0397              ALFA11(I)=ALFA1(I)*57.3
0398              BETA11(I)=BETA1(I)*57.3
0399              ALFA2(I)=ATAN(VU2(I)/VA2(I))
0400              V2(I)=VA2(I)/COS(ALFA2(I))
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0401              V2(I)=SQRT(V2(I)*V2(I)+WR2(I)*WR2(I))
0402              ALFA2(I)=ALFA2(I)*57.3
0403              BETA2(I)=BETA2(I)*57.3
0404              DELH(I)=(U(I)*VU1(I)-U2(I)*VU2(I))/(G*CJ)
0405              TT2(I)=TTO-DELH(I)/CP
0406              PT2(I)=P2(I)*(TT2(I)/T2(I))**EXP1
0407              PT1(I)=P1(I)*(TTO/T1(I))**EXP1
0408              T2IS(I)=TTO*(P2(I)/PTO)**EXP2
0409              T2S(I)=TTE(I)*(P2(I)/PTE(I))**EXP2
0410               TTIS(I)= TTO*(PT2(I)/PTO)**EXP2
0411              BETAT(I)= PTO/PT2(I)
0412              ETAT(I)= (TTO-TT2(I))/(TTO-TTIS(I))
0413              ETAI(I)=(TTO-TT2(I))/(TTO-T2IS(I))
0414              ETAS(I)=(TTO-T1(I))/(TTO-T1IS(I))
0415              ETAR(I)=(TTE(I)-T2(I))/(TTE(I)-T2S(I))
0416              RSTAR(I)=(T1IS(I)-T2IS(I))/(TTO-T2IS(I))
0417              AKIS(I)=2.*G*CJ*CP*(TTO-T2IS(I))/U(I)**2
0418              PSIR(I)=SQRT(ETAR(I))
0419              DR1(I)=RC(I)-RS(I)
0420              AMW1(I)=W1(I)/SQRT(GAM*ERRE*G*T1(I))
0421              AMS1(I)=V1(I)/SQRT(GAM*ERRE*G*T1(I))
0422              AMV2(I)=V2(I)/SQRT(GAM*ERRE*G*T2(I))
0423              AMR2(I)=W2(I)/SQRT(GAM*ERRE*G*T2(I))
0424              BETET(I)=PTE(I)/P2(I)
0425              PRAT1T(I)=PTO/PT1(I)
0426           408 WRITE(6,409) I,RS(I),X1(I),DR1(I),AREA1(I),YS(I),ETAS(I),ZETA1(I),
                 1ZETAPS(I),WPER1(I)
0427              DELH(10)=0.
0428              DO 240 I=1,4
0429              L=I+1
0430           240 DELH(10)=DELH(10)+.5*(WPER2(L)-WPER2(I))*(DELH(L)+DELH(I))
0431              HP=DELH(10)*CJ*WLBM/550.
0432              AMOM=HP*550./OMEG
0433              THETA=SQRT(TTO/518.4)
0434              DELTA=PTO/14.7
0435              HP1=HP/(THETA*DELTA)
0436              AMOM1=AMOM/DELTA
0437              RPM1=RPM/THETA
0438              WLBM1=WLBM*THETA/DELTA
0439              ETA5=(ETAI(1)+ETAI(5)+2.*(ETAI(2)+ETAI(3)+ETAI(4)))/8.
0440               BETA6=(BETAT(1)+BETAT(5) + 2.*(BETAT(2)+BETAT(3) +BETAT(4)))/8.
0441                 ETA6=( ETAT(1)+ ETAT(5) + 2.*( ETAT(2)+ ETAT(3) + ETAT(4)))/8.
0442              AKIS5=(AKIS(1)+AKIS(5)+2.*(AKIS(2)+AKIS(3)+AKIS(4)))/8.
0443              RSTAR5=(RSTAR(1)+RSTAR(5)+2.*(RSTAR(2)+RSTAR(3)+RSTAR(4)))/8.
0444           409 FORMAT(1X,I4,F12.3,F10.3,F9.4,F9.4,F11.4,F11.4,F14.4,F13.4,F14.4)
0445              WRITE(6,412)
0446           412 FORMAT(///22X,23HABSOLUTE VELOCITY (FPS),27X,23HRELATIVE VELOCITY
                 1(FPS)//)
0447           413 FORMAT(1X,6HSTREAM,2X,2(50H  AXIAL      RADIAL   TANGENTIAL   OVER
                 1ALL      ),7H WHEEL )
0448              WRITE(6,413)
0449              WRITE(6,414)
0450           414 FORMAT(1X,6H LINE ,  2(50HCOMPONENT   COMPONENT   COMPONENT    VE
                 1LOCITY     ),8HVELOCITY//)
0451              DO 415 I=1,5
0452           415 WRITE(6,416) I,VA1(I),VR1(I),VU1(I),V1(I),VA1(I),VR1(I),WU1(I),W1(
                 1I),U(I)
0453           416 FORMAT(I5,2X,2(F8.2,3F12.2,6X),F8.2)
0454              WRITE(6,418)
0455           418 FORMAT(///7X,113H      MACH NUMBER                FLOW ANGLE
                 1     TEMPERATURE              PRESSURE                  PRESSURE)
0456              WRITE(6,419)
0457           419 FORMAT(   7X,113H                                    (DEG)
                 1          (DEG. R)              (PSI)                      RATIO  /)
0458              WRITE(6,492)
0459           492 FORMAT(  7H STREAM)
0460              WRITE(6,420)
0461           420 FORMAT(7H  LINE ,2(24H   ABSOLUTE  RELATIVE   ),2(24H     TOTAL
                 1 STATIC    ),24H     TOT/TOT    TOT/STA   /)
0462              DO 422 I=1,5
0463           422 WRITE(6,421)I,AMS1(I),AMW1(I),ALFA11(I),BETA11(I),TTO,T1(I),PT1(I)
                 1,P1(I),PRAT1T(I),PRAT1(I)
0464           421 FORMAT(I4,3X,2F10.2,4X,2F10.2,4X,2F10.2,4X,2F10.3,4X,F11.4,F10.4)
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0465              WRITE(6,999)
0466              WRITE(6,401)
0467              WRITE(6,402)
0468              WRITE(6,403)
0469          452 FORMAT(//57X,21H  ROTOR EXIT SOLUTION///)
0470              IS=2
0471              WRITE(6,405) J,IS,RPM,PR,PTO,TTO
0472              WRITE(6,452)
0473              WRITE(6,406)
0474              WRITE(6,407)
0475              DO 423 I=1,5
0476          423 WRITE(6,409)I,RR(I),X2(I),DR(I),AREA2(I),YR(I),ETAR(I),ZETAR(I),
                 1ZETAPR(I),WPER2(I)
0477              WRITE(6,412)
0478              WRITE(6,413)
0479              WRITE(6,414)
0480              DO 424 I=1,5
0481          424 WRITE(6,416)I,VA2(I),WR2(I),VU2(I),V2(I),VA2(I),WR2(I),WU2(I),W2(I
                 1),U2(I)
0482              WRITE(6,418)
0483              WRITE(6,419)
0484              WRITE(6,492)
0485              WRITE(6,420)
0486              DO 425 I=1,5
0487          425 WRITE(6,421) I,AMV2(I),AMR2(I),ALFA22(I),BETA22(I),TT2(I),T2(I),
                 1PT2(I),P2(I), BETAT(I),PRAT3 (I)
0488              WRITE(6,491)
0489          491 FORMAT(///)
0490              WRITE(6,426)
0491          426 FORMAT(7H STREAM, 74H   EQUIVALENT   EQUIVALENT   EQUIV/STATIC   B
                 1LADE    BLADE      INCIDENCE)
0492          427 FORMAT(7H LINE   , 74H   TEMPERATURE   INLET        PRESSURE       I
                 1NLET    STALL      ANGLE   )
0493          428 FORMAT(  7X,       74H                PRESSURE        RATIO       A
                 1NGLE    ANGLE
0494          429 FORMAT(  7X,       74H    (DEG. R)     (PSI)                       (
                 1DEG)    (DEG)      (DEG)  /)
0495              WRITE(6,427)
0496              WRITE(6,428)
0497              WRITE(6,429)
0498              DO 430 I=1,5
0499          430 WRITE(6,431)I,TTE(I),PTE(I),BETET(I),BETO(I),STALII(I),RINCI(I)
0500          431 FORMAT(I4,F13.2,F13.2,F15.3,F11.1,F9.1,F14.1)
0501              WRITE(6,999)
0502              WRITE(6,401)
0503              WRITE(6,402)
0504              WRITE(6,403)
0505              IS=3
0506              WRITE(6,405)J,IS,RPM,PR,PTO,TTO
0507              WRITE(6,441)
0508          441 FORMAT(//45X,31HOVERALL TURBINE CHARACTERISTICS///)
0509              WRITE(6,442)
0510          442 FORMAT(102H  STREAM       PRESSURE RATIO              EFFICIENCY
                1     HEAD          BLADE/JET     THEORETICAL      )
0511              WRITE(6,443)
0512          443 FORMAT(102H   LINE     TOT/STA    TOT/TOT    TOT/STA      TOT/TOT
                1   COEFFICIENT   SPEED RATIO DEGREE OF REACTION /)
0513              DO 444 I=1,5
0514              BLAJE=1./SQRT(AKIS(I))
0515          444 WRITE(6,445) I,PRAT3(I),BETAT(I),ETAI(I),ETAT(I),AKIS(I),BLAJE,RST
                 1AR(I)
0516          445 FORMAT(I5,F14.4,F11.4,F11.4,F13.4,F12.4,F15.4,F16.4)
0517              WRITE(6,446)
0518          446 FORMAT(///53X,24HMASS AVERAGED QUANTITIES///)
0519          447 FORMAT(52X,13HHCRSE POWER =,F10.2,3X,4H(HP))
0520          448 FORMAT(52X,13HMOMENT      =,F10.2,3X,7H(FT-LB))
0521          449 FORMAT(52X,13HFLOW RATE   =,F10.2,3X,8H(LB/SEC)///)
0522          461 FORMAT(43X,22HREFERRED  RPM       =,F10.2)
0523          462 FORMAT(43X,22HREFERRED HORSE POWER =,F10.2,3X,4H(HP))
0524          463 FORMAT(43X,22HREFERRED MOMENT      =,F10.2,3X,7H(FT-LB))
0525          464 FORMAT(43X,22HREFERRED FLOW RATE   =,F10.2,3X,8H(LB/SEC)///)
0526          465 FORMAT(40X,25HTOTAL/STATIC EFFICIENCY =,F10.4)
0527          466 FORMAT(40X,25HTOTAL/TOTAL  EFFICIENCY =,F10.4//)
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0528          467  FORMAT(36X,29HTOTAL/STATIC PRESSURE RATIO =,F10.4)
0529          468  FORMAT(36X,29HTOTAL/TOTAL  PRESSURE RATIO =, F10.4//)
0530          469  FORMAT(34X,31HHEAD COEFFICIENT                =,F10.4)
0531          471  FORMAT(34X,31HTHEORETICAL DEGREE OF REACTION=,F10.4)
0532          472  FORMAT(34X,31HBLADE/JET SPEED RATIO           =,F10.4)
0533          473  FORMAT(34X,31HMACH NUMBER AT STATION 0        =,F10.4)
0534               WRITE(6,447)HP
0535               WRITE(6,448)AMCM
0536               WRITE(6,449)WL8M
0537               WRITE(6,461)RPM1
0538               WRITE(6,462)HP1
0539               WRITE(6,463)AMCM1
0540               WRITE(6,464)WL8M1
0541               WRITE(6,465)ETA5
0542               WRITE(6,466)ETA6
0543               WRITE(6,467)PRAT5
0544               WRITE(6,468)BETA6
0545               WRITE(6,469)AKIS5
0546               BLAJE5=1./SQRT(AKIS5)
0547               WRITE(6,472)BLAJE5
0548               WRITE(6,471) RSTAR5
0549               WRITE(6,473) AMC
0550               IF(INZ-1)400,930,930
0551           930 IF(N11-1)750,400,400
0552           400 CONTINUE
0553               END
```

```
0001              SUBROUTINE CHAN (TTO,AMC,PTO,RC,WLBM,WCHAN,WPERO)
0002              COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0003              COMMON /CSS/ CJ,G,C1
0004              DIMENSION RC(10),WPERO(10)
0005              TC=TTO/(1.+(GAM-1.)/2.*AMC*AMC)
0006              VC=SQRT(GAM*ERRE*G*TC)*AMC
0007              PC=PTO/(1.+(GAM-1.)*AMC**2/2.)**EXP1
0008              RHO=PC/ERRE/TC
0009              AREA= 3.1416*(RC(5)**2-RC(1)**2)
0010              WLBM=RHO*AREA*VC
0011              WCHAN=WLBM/(PTO*SQRT(G/ERRE/TTO))
0012              WPERO(1)=0.
0013              WPERO(2)=.25
0014              WPERO(3)=.5
0015              WPERO(4)=.75
0016              WPERO(5)=1.
0017              RETURN
0018              END
```

```
0001              SUBROUTINE STATOR (ALFA1,X,TTO,PTO,AM,T,P,V1,VA1,SI1,SI2,Y,S,DSDX,
                 1VU1,PRAT,T1IS,SS,DALF,AA1,BA1,CA1,AA2,BA2,CA2,ALFAM,RSF,DELR,
                 2CL,CK,ZETAPS,R,RS1,RS3,RS5,ZETA,DR,ZETAS,AMS,NS,VR1)
0002              DIMENSION ALFA1(10),X(10),T(10),P(10),V1(10),VA1(10),SI1(10),
                 1SI2(10),Y(10),S(10),DSDX(10),VU1(10),PRAT(10),T1IS(10),SS(10)
                 2,DALDX(10),ALFA(10),DALF(10),ALFAM(10),AMS(10),DALFDX(10),DELR(10)
                 3,ZETAS(10),ETA(10),ZETAPS(10),R(10),ZETA(10),DR(10),VR1(10)
0003              COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0004              COMMON /CSS/ CJ,G,C1
0005              COMMON /IWI/ IND,INZ,IWR
0006              C8=0.0
0007              C9=0.0
0008              C1=2.*CJ*G*CP
0009              C2=VA1(3)**2/(C1*TTO)
0010              DO 303 I=1,5
0011              IF(R(I)-RS3)300,301,302
0012           300 ZETAS(I)=ZETA(1)+(R(I)-RS1)/(RS3-RS1)*(ZETA(3)-ZETA(1))
0013              ALFA1(I)=ALFA1(3)+(R(I)-RS3)/(RS1-RS3)*DALF(1)
0014              ZETAPS(I)=ZETAPS(1)+(R(I)-RS1)/(RS3-RS1)*(ZETAPS(3)-ZETAPS(1))
0015              GO TO 303
0016           301 ZETAS(I)=ZETA(3)
0017              ALFA1(I)=ALFA1(3)
0018              GO TO 303
0019           302 ZETAS(I)=ZETA(3)+(R(I)-RS3)/(RS5-RS3)*(ZETA(5)-ZETA(3))
0020              ALFA1(I)=ALFA1(3)+(R(I)-RS3)/(RS5-RS3)*DALF(5)
0021              ZETAPS(I)=ZETAPS(3)+(R(I)-RS3)/(RS5-RS3)*(ZETAPS(5)-ZETAPS(3))
0022           303 CONTINUE
0023              DO 305 I=1,5
0024              ETA(I)=1.-ZETAS(I)
0025              M=I-1
0026              N=I+1
0027              IF (I-1)307,307,309
0028           307 DALFDX(1)=(ALFA1(2)-ALFA1(1))/(X(2)-X(1))
0029              GO TO 315
0030           309 IF(I-5)311,313,313
0031           311 DALFDX(I)=.5*((ALFA1(N)-ALFA1(I))/(X(N)-X(I))+(ALFA1(I)-ALFA1(M))/
                 1(X(I)-X(M)))
0032              GO TO 315
0033           313 DALFDX(5)=(ALFA1(5)-ALFA1(4))/(X(5)-X(4))
0034           315 TAN1=-2.*TAN(ALFA1(I))
0035              PROD=TAN1*DALFDX(I)
0036              SINSQ=-2.*SIN(ALFA1(I))**2/X(I)
0037              SI1(I)=PROD+SINSQ
0038           305 CONTINUE
0039           304 DO 332 J=1,5
0040              IF(J-1)306,306,310
0041           306 IF(NS-1)317,310,310
0042           317 DO 308 I=1,5
0043              SS(I)=0.
0044           308 SI2(I)=SI1(I)
0045              GO TO 318
0046           310 DO 312 I=1,5
0047              AA=C2*Y(I)**2/COS(ALFA1(I))**2
0048              AB=(1.-AA)/(1.-AA/ETA(I))
0049           312 S(I)=ALOG(AB)
0050           314 DSDX(1)=(S(2)-S(1))/(X(2)-X(1))
0051              DSDX(2)=0.5*(DSDX(1)+(S(3)-S(2))/(X(3)-X(2)))
0052              DSDX(3)=0.5*((S(4)-S(3))/(X(4)-X(3))+(S(3)-S(2))/(X(3)-X(2)))
0053              DSDX(4)=0.5*((S(5)-S(4))/(X(5)-X(4))+(S(4)-S(3))/(X(4)-X(3)))
0054              DSDX(5)=(S(5)-S(4))/(X(5)-X(4))
0055              DO 316 I=1,5
0056              IF(NS-1)319,321,321
0057           319 SS(I)=(1.-COS(ALFA1(I))**2/(C2*Y(I)**2))*DSDX(I)
0058              GO TO 316
0059           321 SS(I)=((-COS(ALFA1(I))**2/(C2*Y(I)**2))+SIN(ALFA1(I))**2+COS(AL
                 1FA1(I))**2*(CL**2+(DR(I)/2.0)**2)/CL**2)*DSDX(I)+COS(ALFA1(I))**2*
                 2CK*2.*RSF*DELR(I)/CL**2
0060           316 SI2(I)= SS(I)+SI1(I)
0061           318 SUM1=(SI2(1)+SI2(2))*(X(2)-X(1))/4.
0062              SUM2=(SI2(2)+SI2(3))*(X(3)-X(2))/4.
0063              SUM3=(SI2(3)+SI2(4))*(X(4)-X(3))/4.
0064              SUM4=(SI2(4)+SI2(5))*(X(5)-X(4))/4.
0065              EN2=-SUM2
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0066              EN1=-SUM2-SUM1
0067              EN3=SUM3
0068              EN4=SUM3+SUM4
0069              Y(1)= EXP(EN1)
0070              Y(2)= EXP(EN2)
0071              Y(3)=1.
0072              Y(4)= EXP(EN3)
0073              Y(5)= EXP(EN4)
0074              IF(IND-1)332,323,323
0075          323 IF(J-1)324,324,320
0076          320 IF(J-3)322,324,322
0077          322 IF(J-5)332,324,332
0078          324 WRITE (6,326)
0079          326 FORMAT (/57H SLINE  C8  C9  ITERATION  I'ALFA  I'DSDX  I'TOTAL
                 1  Y)
0080              DO 330 I=1,5
0081          328 FORMAT (I4,F4.2,F4.2,I9,F12.4,F9.5,F9.4,2F8.4)
0082          330 WRITE (6,328) I,C8,C9,J,SI1(I),SS(I),SI2(I),Y(I),ALFA1(I)
0083          332 CONTINUE
0084              DO 334 I=1,5
0085              VA1(I)=VA1(3)*Y(I)
0086              VU1(I)=VA1(I)*TAN(ALFA1(I))
0087              V1(I)=VA1(I)/COS(ALFA1(I))
0088              VR1(I)=-VA1(I)*DR(I)/2./CL
0089              V1(I)=SQRT(V1(I)*V1(I)+VR1(I)*VR1(I))
0090              T(I)=TTO-V1(I)**2/C1
0091              T1IS(I)=TTO-(TTO-T(I))/ETA(I)
0092              P(I)=PTO*(T1IS(I)/TTO)**EXP1
0093          334 PRAT(I)=P(I)/PTO
0094              C9=C9+1.
0095              IF(C9-2.)336,356,356
0096          336 DO 352 I=1,5
0097              AMS(I)=V1(I)/SQRT(GAM*ERRE*G*T (I))
0098              IF (AMS(I)-.75)338,344,346
0099          338 IF (AMS(I)-.5)340,340,342
0100          340 ALFA(3)=ALFAM(1)
0101              GO TO 348
0102          342 ALFA(3)=AA1+BA1*AMS(I)+CA1*AMS(I)**2
0103              GO TO 348
0104          344 ALFA(3)=ALFAM(3)
0105              GO TO 348
0106          346 ALFA(3)=AA2+BA2*AMS(I)+CA2*AMS(I)**2
0107          348 IF(R(I)-RS3)339,350,341
0108          339 ALFA1(I)=ALFA(3)+(R(I)-RS3)/(RS1-RS3)*DALF(1)
0109              GO TO 352
0110          350 ALFA1(I)=ALFA(3)
0111              GO TO 352
0112          341 ALFA1(I)=ALFA(3)+(R(I)-RS3)/(RS5-RS3)*DALF(5)
0113          352 CONTINUE
0114              DO 354 I=1,5
0115              M=I-1
0116              N=I+1
0117              IF (I-1)347,347,349
0118          347 DALFDX(1)=(ALFA1(2)-ALFA1(1))/(X(2)-X(1))
0119              GO TO 355
0120          349 IF(I-5)351,353,353
0121          351 DALFDX(I)=.5*((ALFA1(N)-ALFA1(I))/(X(N)-X(I))+(ALFA1(I)-ALFA1(M))/
                 1(X(I)-X(M)))
0122              GO TO 355
0123          353 DALFDX(5)=(ALFA1(5)-ALFA1(4))/(X(5)-X(4))
0124          355 TAN1=-2.*TAN(ALFA1(I))
0125              PROD=TAN1*DALFDX(I)
0126              SINSQ=-2.*SIN(ALFA1(I))**2/X(I)
0127              SI1(I)=PROD+SINSQ
0128          354 CONTINUE
0129              GO TO 304
0130          356 RETURN
0131              END
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0001            OSUBROUTINE ROTOR1(VU1,VA1,RPM,U,BETA1,HE,TTE,PTE,X2,P1,T1,W1,WU1,
                1X1,RS,ZETAR,ZETAPR,RR,DHEDX,DSDX,S,U2,OMEG,BR1,BR2,BR3,FS1,FS2,
                2ZETA     ,B6,RS1,RS3,RS5,BETO,STALI,BINC,VR1)
0002            OCIMENSION VU1(10),VA1(10),U(10),BETA1(10),HE(10),TTE(10),PTE(10),
                1X2(10),P1(10),T1(10),W1(10),WU1(10),X1(10),RS(10),ZETAR(10),
                2ZETAPR(10),RR(10),DHEDX(10),DSDX(10),S(10),U2(10),ZETA(10)
                3 ,VR1(10)              ,B6(20),BETO(10),STALI(10),BINC(10)
0003             COMMON /CSS/ CJ,G,C1
0004             COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0005             COMMON /IWI/ INC,INZ,IWR
0006             C=2.*32.174*778.16*CP
0007             OMEG=RPM*3.1416/30.
0008             DO 520 I=1,5
0009             U(I)=OMEG*RS(I)/12.
0010             U2(I)=U(I)*RR(I)/RS(I)
0011             WU1(I)=VU1(I)-U(I)
0012             BETA1(I)=ATAN(WU1(I)/VA1(I))
0013             W1(I)=VA1(I)/COS(BETA1(I))
0014             W1(I)=SQRT(VR1(I)*VR1(I)+W1(I)*W1(I))
0015             TTE(I)=T1(I)+W1(I)**2/C+(U2(I)**2-U(I)**2)/C
0016             PTE(I)=P1(I)*(TTE(I)/T1(I))**EXP1
0017             HE(I)=TTE(I)*.24
0018             BETO(I)=BR1+FS1*BR2*X1(I)+FS2*BR3*X1(I)**2
0019             STALI(I)=B6(1)+B6(2)*RS(I)+B6(3)*RS(I)**2+B6(4)*RS(I)**3+B6(5)*RS
                1(I)**4
0020             BINC(I)=BETA1(I)-BETO(I)/57.3
0021             IF(RS(I)-RS3)512,514,516
0022          512 ZETAR(I)=ZETA(1)+(RS(I)-RS1)/(RS3-RS1)*(ZETA(3)-ZETA(1))
0023             GO TO 518
0024          514 ZETAR(I)=ZETA(3)
0025             GO TO 518
0026          516 ZETAR(I)=ZETA(3)+(RS(I)-RS3)/(RS5-RS3)*(ZETA(5)-ZETA(3))
0027          518 ZETAPR(I)=ZETAR(I)/2.0
0028          520 CONTINUE
0029             DSDX(1)=(S(2)-S(1))/(X2(2)-X2(1))
0030             DSDX(2)=0.5*(DSDX(1)+(S(3)-S(2))/(X2(3)-X2(2)))
0031             DSDX(3)=0.5*((S(4)-S(3))/(X2(4)-X2(3))+(S(3)-S(2))/(X2(3)-X2(2)))
0032             DSDX(5)=(S(5)-S(4))/(X2(5)-X2(4))
0033             DSDX(4)=0.5*(DSDX(5)+(S(4)-S(3))/(X2(4)-X2(3)))
0034             DHEDX(1)=(HE(2)-HE(1))/(X2(2)-X2(1))
0035             DHEDX(2)=0.5*(DHEDX(1)+(HE(3)-HE(2))/(X2(3)-X2(2)))
0036            QDHEDX(3)=0.5*((HE(3)-HE(2))/(X2(3)-X2(2))+(HE(4)-HE(3))/
                1 (X2(4)-X2(3)))
0037             DHEDX(5)=(HE(5)-HE(4))/(X2(5)-X2(4))
0038             DHEDX(4)=0.5*(DHEDX(5)+(HE(4)-HE(3))/(X2(4)-X2(3)))
0039          522 CONTINUE
0040             RETURN
0041             END
```

```
0001              SUBROUTINE ROTOR2 (BETA2,HE,DHEDX,DSDX1,DSDX2,VA2,WU2,W2,VU2,V2,
                 1X2,U,YR,ZETAR,RI1,RI2,RI3,RI4,RI,SR1,SR2,AA,SR,TTE,PTE,T2,P2,PRAT2
                 2,T2S,INDS,DBET,BETAM,AB1,BB1,CB1,AB2,BB2,CB2,RRF,DELR,CL,CK,DR,R,
                 3RR1,RR3,RR5,NS,WR2)
0002              DIMENSION BETA2(10),HE(10),DHEDX(10),DSDX1(10),DSDX2(10),VA2(10),
                 1WU2(10),W2(10),VU2(10),V2(10),X2(10),U(10),YR(10),ZETAR(10),
                 2RI1(10),RI2(10),RI3(10),RI4(10),RI(10),SR1(10),SR2(10),YOLD(10),
                 3AA(10),SR(10),TTE(10),PTE(10),T2(10),P2(10),PRAT2(10),T2S(10),
                 4DBET(10),BETAM(10),AMR(10),DBETDX(10),BETA(10),DELR(10),RI5(10)
                 5,DR(10),R(10),WR2(10)
0003               COMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0004               COMMON /CSS/ CJ,G,C1
0005               COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0006               COMMON /IWI/ IND,IN2,IWR
0007               INDS=0
0008               INDS1=0
0009               C=2.*G*CJ
0010               C1=C/VA2(3)**2
0011               DO 274 I=1,5
0012               IF(R(I)-RR3)270,271,273
0013          270  BETA2(I)=BETA2(3)+(R(I)-RR3)/(RR1-RR3)*DBET(1)
0014               GO TO 274
0015          271  BETA2(I)=BETA2(3)
0016               GO TO 274
0017          273  BETA2(I)=BETA2(3)+(R(I)-RR3)/(RR5-RR3)*DBET(5)
0018          274  CONTINUE
0019               DBETDX(1)=(BETA2(2)-BETA2(1))/(X2(2)-X2(1))
0020               DBETDX(5)=(BETA2(5)-BETA2(4))/(X2(5)-X2(4))
0021               DO 280 I=2,4
0022               M=I-1
0023               N=I+1
0024          280  DBETDX(I)=.5*((BETA2(N)-BETA2(I))/(X2(N)-X2(I))+(BETA2(I)-BETA2
                  1(M))/(X2(I)-X2(M)))
0025               DO 10 I=1,5
0026          200  TAN1=-2.*TAN(BETA2(I))
0027               PROD=TAN1*DBETDX(I)
0028               SIN1=-2.*SIN(BETA2(I))**2/X2(I)
0029               RI1(I)=PROD+SIN1+DSDX1(I)
0030               SR1(I)=-4.*U(3)*COS(BETA2(I))*SIN(BETA2(I))/(VA2(3)*YR(I))
0031               SR2(I)=2.*U(3)*U(I)*COS(BETA2(I))**2/(VA2(3)**2*YR(I)**2)
0032               YCLD(I)=YR(I)
0033               AA(I)=(VA2(3)*YR(I)/COS(BETA2(I)))**2/(C*HE(I))
0034               RI3(I)=C*COS(BETA2(I))**2/(VA2(3)*YR(I))**2*DHEDX(I)
0035               IF (INDS1-1)10,250,250
0036            10 CONTINUE
0037          281  IF(IND-1)201,282,282
0038          282  WRITE (6,121)(RI1(I),I=1,5)
0039          121  FORMAT(/23H CONSTANT INTEGRAND 1-5, 5F8.5)
0040               WRITE (6,122)
0041          122  FORMAT(/60H SLINE  INDS1  GRAD S   INT2   INT3    INT4    INT
                  1Y VAL)
0042          201  DO 20 J=1,13
0043               DO 30 I=1,5
0044               AA(I)=AA(I)*(YR(I)/YOLD(I))**2
0045               ANUM=1.-AA(I)
0046               ADEN=1.-AA(I)/(1.-ZETAR(I))
0047               AB=ANUM/ADEN
0048               IF (AB) 130,130,30
0049          130  INDS=1
0050               GO TO 150
0051            30 SR(I)=ALOG(ANUM/ADEN)
0052               DSDX2(1)=(SR(2)-SR(1))/(X2(2)-X2(1))
0053               DSDX2(2)=0.5*(DSDX2(1)+(SR(3)-SR(2))/(X2(3)-X2(2)))
0054               DSDX2(3)=0.5*((SR(3)-SR(2))/(X2(3)-X2(2))+(SR(4)-SR(3))/
                  1 (X2(4)-X2(3)))
0055               DSDX2(5)=(SR(5)-SR(4))/(X2(5)-X2(4))
0056               DSDX2(4)=0.5*(DSDX2(5)+(SR(4)-SR(3))/(X2(4)-X2(3)))
0057               DO 40 I=1,5
0058               SR1(I)=SR1(I)*YCLD(I)/YR(I)
0059               SR2(I)=SR2(I)*(YOLD(I)/YR(I))**2
0060               RI2(I)=SR1(I)-SR2(I)
0061               RI3(I)=RI3(I)*(YOLD(I)/YR(I))**2
0062               IF(NS-1)31,32,32
```

```
0063          31 RI4(I)=DSDX2(I)-(DSDX1(I)+DSDX2(I))*C1*HE(I)
                1 *(COS(BETA2(I))/YR(I))**2
0064               GO TO 40
0065          32 RI4(I)=-(DSDX1(I)+DSDX2(I))*C1*HE(I)*(COS(BETA2(I))/YR(I))**2
0066               RI5(I)=(DSDX1(I)+DSDX2(I))*(SIN(BETA2(I))**2+COS(BETA2(I))**2
                  1*((CL**2+(DR(I)/2.0)**2)/CL**2)-COS(BETA2(I))**2*(2.*CK*RRF*
                  2DELR(I))/CL**2
0067               RI4(I)=RI4(I)+RI5(I)
0068          40 RI(I)=RI1(I)+RI2(I)+RI3(I)+RI4(I)
0069               SUM1=(RI(1)+RI(2))*(X2(2)-X2(1))/4.
0070               SUM2=(RI(2)+RI(3))*(X2(3)-X2(2))/4.
0071               SUM3=(RI(3)+RI(4))*(X2(4)-X2(3))/4.
0072               SUM4=(RI(4)+RI(5))*(X2(5)-X2(4))/4.
0073               EN1=-(SUM2+SUM1)
0074               EN2=-SUM2
0075               EN4=SUM3
0076               EN5=SUM3+SUM4
0077               DO 50 I=1,5
0078          50 YOLD(I)=YR(I)
0079               YR(1)= EXP(EN1)
0080               YR(2)= EXP(EN2)
0081               YR(3)=1.0
0082               YR(4)= EXP(EN4)
0083               YR(5)= EXP(EN5)
0084               NCOUNT=0
0085               DO 1001 I=1,5
0086               IF( YR(I).GT. 2.0) YR(I)= 2.0
0087               IF( YR(I).LT. 0.2) YR(I)= 0.2
0088         1001   CONTINUE
0089               DO 110 I=1,5
0090               TEST=ABS(YOLD(I)-YR(I))
0091               IF(TEST-TOL4)110,110,119
0092          110 NCOUNT=NCOUNT+1
0093               IF(NCOUNT-5)119,140,119
0094          119 IF(IND-1)20,120,120
0095          120 IF (J-3) 80,100,80
0096           80 IF (J-6) 90,100,90
0097           90 IF (J-9) 160,100,160
0098          160 IF (J-12) 20,100,20
0099          100 DO 60 I=1,5
0100          123 FORMAT (I4,I7,F10.5,5F8.4)
0101           60 WRITE (6,123) I,INDS1,DSDX2(I),RI2(I),RI3(I),RI4(I),RI(I),YR(I)
0102           20 CONTINUE
0103          140 DO 70 I=1,5
0104               VA2(I)=YR(I)*VA2(3)
0105               W2(I)=VA2(I)/COS(BETA2(I))
0106               WR2(I)=-VA2(I)*DR(I)/2./CL
0107               W2(I) =SQRT(W2(I)*W2(I)+WR2(I)*WR2(I))
0108           70 T2(I)=TTE(I)-W2(I)**2/(0.24*C)
0109               IF(INDS1-1)251,149,149
0110          251 INDS1=INDS1+1
0111               DO 250 I=1,5
0112               AMR(I)=W2(I)/SQRT(GAM*ERRE*G*T2(I))
0113               IF(AMR(I)-.75)1,4,5
0114            1 IF(AMR(I)-.512)2,2,3
0115            2 BETA(3)=BETAM(1)
0116               GO TO 6
0117            3 BETA(3)=AB1+BB1*AMR(I)+CB1*AMR(I)**2
0118               GO TO 6
0119            4 BETA(3)=BETAM(3)
0120               GO TO 6
0121            5 BETA(3)=AB2+BB2*AMR(I)+CB2*AMR(I)**2
0122            6 IF (R(I)-RR3)221,222,223
0123          221 BETA2(I)=BETA(3)+(R(I)-RR3)/(RR1-RR3)*DBET(1)
0124               GO TO 250
0125          222 BETA2(I)=BETA(3)
0126               GO TO 250
0127          223 BETA2(I)=BETA(3)+(R(I)-RR3)/(RR5-RR3)*DBET(5)
0128          250 CONTINUE
0129               DBETDX(1)=(BETA2(2)-BETA2(1))/(X2(2)-X2(1))
0130               DBETDX(5)=(BETA2(5)-BETA2(4))/(X2(5)-X2(4))
0131               DO 224 I=2,4
0132               M=I-1
```

```
0133              N=I+1
0134          224 DBETDX(I)=.5*((BETA2(N)-BETA2(I))/(X2(N)-X2(I))+(BETA2(I)-BETA2
                 1(M))/(X2(I)-X2(M)))
0135              DO 225 I=1,5
0136              TAN1=-2.*TAN(BETA2(I))
0137              PROD=TAN1*DBETDX(I)
0138              SIN1=-2.*SIN(BETA2(I))**2/X2(I)
0139              RI1(I)=PROD+SIN1+DSDX1(I)
0140              SR1(I)=-4.*U(3)*COS(BETA2(I))*SIN(BETA2(I))/(VA2(3)*YR(I))
0141              SR2(I)=2.*U(3)*U(I)*COS(BETA2(I))**2/(VA2(3)**2*YR(I)**2)
0142              YOLD(I)=YR(I)
0143              AA(I)=(VA2(3)*YR(I)/COS(BETA2(I)))**2/(C*HE(I))
0144              RI3(I)=C*COS(BETA2(I))**2/(VA2(3)*YR(I))**2*DHEDX(I)
0145          225 CONTINUE
0146              GO TO 281
0147          149 DO 190 I=1,5
0148              WU2(I)=VA2(I)*TAN(BETA2(I))
0149              VU2(I)=WU2(I)+U(I)
0150              T2S(I)=TTE(I)-(TTE(I)-T2(I))/(1.-ZETAR(I))
0151              P2(I)=PTE(I)*(T2S(I)/TTE(I))**(GAM/(GAM-1.))
0152          190 PRAT2(I)=P2(I)/PTE(I)
0153          150 RETURN
0154              END
```

```
0001              SUBROUTINE FLOWR(PRAT,ZETAP,X,WI,PTE,PTO,TTE,TTO,AS,ZS,RS,AM,ZR,
                 1RR,M,WCHAN,VA,WPER,CODE,WLBM,B,R,TIPC,A)
0002              DIMENSION PRAT(10),ZETAP(10),X(10),WI(10),PTE(10),TTE(10),
                 1VA(10),WPER(10),B(20),A(10),R(10)
0003               COMMON /CUR/ COSL(10)
0004               COMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0005                COMMON /MAC/ IN
0006               COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0007               COMMON /CSS/ CJ,G,CI
0008               COMMON /ABA/ BA17,BLEX
0009               COMMON /IWI/ IND,INZ,IWR
0010                IN= 20
0011               C=BLEX
0012               A(3)=B(1)+B(2)*R(3)+B(3)*R(3)**2+B(4)*R(3)**3+B(5)*R(3)**4
0013               F1=1./(C+1.)
0014               F2=1./(3.*C+1.)
0015               F3=1./(5.*C+1.)
0016               F4=1./(7.*C+1.)
0017               F5=1./(9.*C+1.)
0018               F6=1./(11.*C+1.)
0019               PRATCR=(2./(GAM+1.))**(GAM/(GAM-1.))
0020               PHICR=(2./(GAM+1.))**(1./(GAM-1.))*SQRT(2.*GAM/(GAM+1.))
0021               DO 420 I=1,5
0022               IF (PRATCR-PRAT(I))400,402,402
0023           400 XE=1.-PRAT(I)**((GAM-1.)/GAM)
0024               GO TO 404
0025           402 XE=1.-PRATCR**((GAM-1.)/GAM)
0026           404 XE2=XE**2
0027               XE3=XE**3
0028               XE4=XE**4
0029               XEINV=1./(XE-1.)
0030               HNUM=XEINV+F2+XE*F3+XE2*F4+XE3*F5+XE4*F6
0031               HDEN=XEINV+F1+XE*F2+XE2*F3+XE3*F4+XE4*F5
0032               HSTAR=HNUM/HDEN
0033               XI=(HSTAR-1.)/(HSTAR-1.+ZETAP(I))
0034               IF (PRATCR-PRAT(I))406,408,408
0035           406 PHI=SQRT(2.*GAM/(GAM-1.)*(PRAT(I)**(2./GAM)-PRAT(I)**
                 1 ((GAM+1.)/GAM)))
0036               GO TO 410
0037           408 PHI=PHICR
0038           410 A(I)=B(1)+B(2)*R(I)+B(3)*R(I)**2+B(4)*R(I)**3+B(5)*R(I)**4
0039               ARAT=A(I)/A(3)
0040               IF(M-2)415,412,415
0041           412 IF(I-5)415,414,414
0042           414 ARAT=ARAT+2.*3.1416*R(5)*TIPC/(ZR*AR*RR*(X(5)-X(4)))
0043           415 IF(IND-1)420,416,416
0044           416 WRITE (6,418) XI,PHI,ARAT
0045           418 FORMAT (/5H  XI=, F6.4, 6H  PHI=, F7.5, 7H  ARAT=,F6.4)
0046           420 WI(I)=(PTE(I)/PTO)/SQRT(TTE(I)/TTO)*ARAT*XI*PHI*COSL(I)
0047               SUM1=(WI(1)+WI(2))*(X(2)-X(1))/2.
0048               SUM2=(WI(2)+WI(3))*(X(3)-X(2))/2.
0049               SUM3=(WI(3)+WI(4))*(X(4)-X(3))/2.
0050               SUM4=(WI(4)+WI(5))*(X(5)-X(4))/2.
0051               WSUM=SUM1+SUM2+SUM3+SUM4
0052               IF (M-1)428,426,428
0053           426 WREQ=WCHAN/(AS*ZS*RS)
0054               DIFF=ABS(WREQ-WSUM)
0055               GO TO 430
0056           428 WREQ=WCHAN/(AR*ZR*RR)
0057               DIFF=ABS(WREQ-WSUM)
0058           430  TAL= TOL1*WREQ
0059               IF (DIFF-TAL  )432,432,434
0060           432 VA(3)=VA(3)
0061               CODE=20.
0062               GO TO 442
0063           434 IF(WSUM-WREQ)436,432,438
0064           436  CONTINUE
0065               IF( PRAT(1).LT.PRATCR. AND. PRAT(5) .LT. PRATCR  ) GOTO 470
0066               VA(3)=VA(3)*(1.00+ DIFF/WREQ*1.01)
0067               GO TO 442
0068           438 VA(3)=VA(3)*(1.00- DIFF/WREQ*1.01)
0069           442 WPER(1)=0.
0070               WPER(2)=SUM1/WSUM
```

```
0071              WPER(3)=(SUM1+SUM2)/WSUM
0072              WPER(4)=(SUM1+SUM2+SUM3)/WSUM
0073              WPER(5)=1.
0074              IF(IND-1)450,422,423
0075            423 WRITE (6,422) (WI(I),I=1,5)
0076            422 FORMAT (/20H  FLOW INTEGRAND 1-5, 5F10.5)
0077              WRITE (6,424) SUM1,SUM2,SUM3,SUM4,WSUM
0078            424 FORMAT (/15H SUMS 1-4, WSUM, 5F10.5)
0079              WRITE (6,440) WSUM,WREQ,VA(3)
0080            440 FORMAT(35H REF FLOWS,COMPUTED-REQUIRED,AX VEL,2F10.4,F10.2)
0081              WRITE (6,444) WCHAN,WLBM
0082            444 FORMAT(/36H REF FLOW RATE CHANNEL-SQUARE INCHES,F8.5,18H FLOW RATE
                   1-LBM/SEC,F8.5)
0083              WRITE (6,446) M
0084            446 FORMAT (/30H STREAMLINE FLOW FRACTIONS, M=,I2)
0085              WRITE (6,448) X(2),WPER(2),X(3),WPER(3),X(4),WPER(4)
0086            448 FORMAT(6F10.4)
0087               GOTO 450
0088            470   IN=1
0089            450 RETURN
0090              END
```

```
0001            OSUBROUTINE SLINE (RR,X,DWDX,WPER2,WPER1,HE,U,DHEDX,S,DSDX1,
                1ARF,RRF,FC1,FC2,CODE,M,B)
0002            ODIMENSION RR(10),X(10),DWDX(10),WI(10),WPER2(10),WPER1(10),HE(10),
                1DHEDX(10),S(10),DSDX1(10),U(10),B(20)
0003             COMMON /TOL/ TOL1,TOL2,TOL3,TOL4
0004             CCMMON /IWI/ INC,INZ,IWR
0005             N7=0
0006             SAVE=RR(3)
0007             CODE=1.
0008             DO 700 I=1,4
0009             J=I+1
0010          700 DWDX(I)=(WPER2(J)-WPER2(I))/(X(J)-X(I))
0011             N=0
0012             DO 720 I=2,4
0013             K=I+1
0014             J=I-1
0015             IF (ABS(WPER2(I)-WPER1(I))-TOL2)716,716,702
0016          702 IF (WPER2(I)-WPER1(I))704,716,708
0017          704 XN=X(I)+(WPER1(I)-WPER2(I))/DWDX(J)
0018             IF(M-1)706,712,706
0019          706 SL=(HE(K)-HE(I))/(X(K)-X(I))
0020             DEL=2.*(SL-DHEDX(I))/(X(K)-X(I))
0021             DHEDX(I)=DHEDX(I)+DEL*(XN-X(I))
0022             HE(I)=HE(I)+DHEDX(I)*(XN-X(I))
0023             SL=(S(K)-S(I))/(X(K)-X(I))
0024             DEL=2.*(SL-DSDX1(I))/(X(K)-X(I))
0025             DSDX1(I)=DSDX1(I)+DEL*(XN-X(I))
0026             S(I)=S(I)+DSDX1(I)*(XN-X(I))
0027             GO TO 712
0028          708 XN=X(I)-(WPER2(I)-WPER1(I))/DWDX(I)
0029             IF (M-1)710,712,710
0030          710 SL=(HE(I)-HE(J))/(X(I)-X(J))
0031             DEL=2.*(DHEDX(I)-SL)/(X(I)-X(J))
0032             DHEDX(I)=DHEDX(I)+DEL*(XN-X(I))
0033             HE(I)=HE(I)+DHEDX(I)*(XN-X(I))
0034             SL=(S(I)-S(J))/(X(I)-X(J))
0035             DEL=2.*(DSDX1(I)-SL)/(X(I)-X(J))
0036             DSDX1(I)=DSDX1(I)+DEL*(XN-X(I))
0037             S(I)=S(I)+DSDX1(I)*(XN-X(I))
0038          712 RR(I)=XN*SAVE
0039             GO TO 718
0040          716 N=N+1
0041             IF (N-3)720,730,720
0042          718 U(I)=U(I)*XN/X(I)
0043          720 CONTINUE
0044             DO 722 I=1,5
0045          722 X(I)=RR(I)/RR(3)
0046             FC1=RR(3)/SAVE
0047             FC2=FC1**2
0048             RRF=RR(3)
0049             ARF=B(1)+B(2)*RRF+B(3)*RRF**2+B(4)*RRF**3+B(5)*RRF**4
0050             IF(IND-1)732,721,721
0051          721 IF (M-1)729,732,729
0052          729 WRITE (6,724)
0053          724 FORMAT (/47H SLINE  XNEW    HENEW     DHEDX      S-NEW    DSDX1)
0054             DO 728 I=1,5
0055          726 FORMAT (I4,F9.4,F9.2,F9.4,F9.6,F9.5)
0056          728 WRITE (6,726) I,X(I),HE(I),DHEDX(I),S(I),DSDX1(I)
0057             GO TO 732
0058          730 CODE=40.
0059          732 RETURN
0060             END
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0001              SUBROUTINE ALOS1(ZETAS,ZETAPS)
0002              DIMENSION  ALFA1(10),V1(10),RS(10),P1(10),T1(10),U (10),AMS1(10),
                 1ZETAS(10),ZETAPS(10)
0003              COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0004              COMMON /CSS/ CJ,G,CI
0005              COMMON /AL1/  ALFA1,V1,TTO,RPM,RS,SI,TNI,H,D,CI,T1,P1,TO,TEI,ALI,
                 1BESP,XX,ANG2O,AMS1,S,TN,C,TE,AL,SO,TNO,CO,TEO,U ,D1I,D1O,D2I,D2O,
                 2ANG2I,ALFAX,TI,T,PTO,ALO,AMC
0006              COMMON /IWI/ IND,INZ,IWR
0007              COMMON /AUS/ XCL
0008              COMMON /ARE/ REE
0009              COMMON /COZ/ ICOR,ICOZ,IINC,IAI,ICL,IAN,ICON
0010              COMMON /ABA/ BA17,BLEX
0011              COMMON /TR5/ TRA5
0012              IF(ICOR.NE.1)GOTO 5999
0013              RO=P1(3)/T1(3)*144./ERRE
0014              REE=RO*V1(3)*C/12./VIS2
0015              IF(ICL.EQ.0.AND.IAI.EQ.0)B=.5
0016              IF(ICL.EQ.1.AND.IAI.EQ.0)B=.25
0017              IF(ICL.EQ.0.AND.IAI.EQ.1)B=.47
0018              IF(ICL.EQ.1.AND.IAI.EQ.1)B=.37
0019              CALL AINLOS(0.,ANG2I,SI,CI,TI,D1I,D1O,D2I,D2O,0.,H,IWR,ZI1,ZI2,ZI3
                 1,0.,100.,B,TNI)
0020              CALL AINLOS(0.,ALFAX,S ,C ,T ,D1I,D1O,D2I,D2O,0.,H,IWR,Z1 ,Z2 ,Z3
                 1,0.,100.,B,TN )
0021              CALL AINLOS(0.,ANG2O,SO,CO,TO,D1I,D1O,D2I,D2O,0.,H,IWR,ZO1,ZO2,ZO3
                 1,0.,100.,B,TNO)
0022              ZETAS(1)=ZI3/(1.+ZI3)
0023              ZETAS(3)=Z3 /(1.+Z3 )
0024              ZETAS(5)=ZO3/(1.+ZO3)
0025              GOTO 2020
0026         5999 CONTINUE
0027              IF(ICOR.NE.4)GOTO 6000
0028              DO 6001 MACC=1,5,2
0029              TRA1=90.-ALFA1(MACC)*57.29578
0030              TRA2=V1(MACC)*.3048
0031              TRA3=TTO/1.8
0032              TRA4=RPM*3.14159/30.*RS(MACC)/12.*.3048
0033              IF(MACC-3) 6002,6003,6004
0034         6002 CALL TRAUP2(TRA1,90.,TRA2,TRA3,EMME,GAM,SI,TNI,H,D,TRA5,CI,TRA4,
                10.,TR16,TRA7,TRA8,TRA9,ZETAS(MACC))
0035              GOTO 6001
0036         6003 CALL TRAUP2(TRA1,90.,TRA2,TRA3,EMME,GAM,S,TN ,H,D,TRA5,C ,TRA4,
                10.,TR26,TRA7,TRA8,TRA9,ZETAS(MACC))
0037              GOTO 6001
0038         6004 CALL TRAUP2(TRA1,90.,TRA2,TRA3,EMME,GAM,SO,TNO,H,D,TRA5,CO,TRA4,
                10.,TR36,TRA7,TRA8,TRA9,ZETAS(MACC))
0039         6001 CONTINUE
0040         6000 CONTINUE
0041              IF(ICOR.NE.3) GOTO 2001
0042              XXX2=AMC*SQRT(TTO)
0043              DO 2003 MACC=1,5
0044              XXX1=-ALFA1(MACC)
0045              XXX3=AMS1(MACC)*SQRT(T1(MACC))
0046         2003  ZETAS(MACC) = ZA1LOS( 0.,XXX1,XXX2, XXX3)
0047         2001 CONTINUE
0048              IF(ICOR.NE.2) GOTO 2020
0049              BAL1=3.14159/2.
0050              BAL5=D+H
0051              F1=1.*BLEX+1.
0052              F2=3.*BLEX+1.
0053              F3=5.*BLEX+1.
0054              F4=7.*BLEX+1.
0055              F5=9.*BLEX+1.
0056              F6=11.*BLEX+1.
0057              G1=F1+BLEX
0058              G2=F2+BLEX
0059              G3=F3+BLEX
0060              G4=F4+BLEX
0061              G5=F5+BLEX
0062              G6=F6+BLEX
0063              DO 202 MACC=1,5,2
0064              XE=1.-(P1(MACC)/PTO)**EXP2
```

```
0065              ANUM=1.-(1.-XE)*(1./F1+XE/F2+XE**2/F3+XE**3/F4+XE**4/F5+XE**5/F6)
0066              ADEN=1-ANUM-(1.-XE)*(1./G1+XE/G2+XE**2/G3+XE**3/G4+XE**4/G5+XE**5/
                 1G6)
0067              XX=ANUM/ADEN
0068              BAL2=BAL1-ALFA1(MACC)
0069              BAL3=P1(MACC)/T1(MACC)/ERRE*12.
0070              BAL4=RPM*3.14159/30.*RS(MACC)/12.
0071              IF(MACC-3) 2022,2023,2024
0072           2022 CALL BALJE(BAL1,BAL2,AL1,CI,SI,TEI,BAL3,VIS2,BAL4,BAL5,XX,0.,IWR,0
                 1,BA16,BAL7,BAL8,V1(MACC),H)
0073              BAL6=BA16
0074              GOTO 2025
0075           2023 CALL BALJE(BAL1,BAL2,AL ,C ,S ,TE ,BAL3,VIS2,BAL4,BAL5,XX,0.,IWR,0
                 1,BA26,BAL7,BAL8,V1(MACC),H)
0076              BAL6=BA26
0077              BAL7=BAL7
0078                GO TO 2025
0079           2024 CALL BALJE(BAL1,BAL2,ALO,CO,SO,TEO,BAL3,VIS2,BAL4,BAL5,XX,0.,IWR,0
                 1,BA36,BAL7,BAL8,V1(MACC),H)
0080              BAL6=BA36
0081           2025  ZETAS(MACC) = BAL6 +BAL7+ BAL8
0082           2021    CONTINUE
0083           2020    CONTINUE
0084              IF(ICOZ.LT.5) GOTO 2026
0085              DO 2027 MACC=1,6,2
0086              XY=ZETAS(MACC)/(1.-ZETAS(MACC))
0087              ZETAS(MACC)=(((1.+XY)/(  1.+XY*P1(MACC)/PTO)) **EXP2-1.)/
                 1((PTO/P1(MACC))**EXP2-1.)
0088              IF(ICOZ.EQ.8) ZETAS(MACC)=(((1.+XY)/(1.+XY*BESP))**EXP2-1.)/
                 1(1./BESP**EXP2-1.)
0089           2027  CONTINUE
0090           2026 CONTINUE
0091              IF(ICON.NE.3) GOTO 31
0092             30 DO 32 I=1,5,2
0093             32 ZETAPS(I)=ZETAS(I)
0094             31 IF(ICON.NE.2)GOTO 33
0095                IF(ICOR.EQ.4)ZETAPS(1)=TR16
0096                IF(ICOR.EQ.4)ZETAPS(3)=TR26
0097                IF(ICOR.EQ.4)ZETAPS(5)=TR36
0098                IF(ICOR.EQ.2)ZETAPS(1)=BA16
0099                IF(ICOR.EQ.2)ZETAPS(3)=BA26
0100                IF(ICOR.EQ.2)ZETAPS(5)=BA36
0101                IF(ICOR.EQ.1)ZETAPS(1)=ZI1/(1.+ZI1)
0102                IF(ICOR.EQ.1)ZETAPS(3)=ZI /(1.+ZI )
0103                IF(ICOR.EQ.1)ZETAPS(5)=ZO1/(1.+ZO1)
0104             33 CONTINUE
0105                IF(ICON.NE.1)GOTO 34
0106                DO 35 I=1,5,2
0107             35 ZETAPS(I)=ZETAS(I)
0108             34 CONTINUE
0109                RETURN
0110                END
```

```
0001              SUBROUTINE ALOS2(ZETAR,ZETAPR)
0002              DIMENSION  ALFA1(10),V1(10),RS(10),P1(10),T1(10),U (10),AMS1(10),
                 1ZETAS(10),ZETAPS(10)
0003              DIMENSION  BETA2(10),W2(10),RR(10),P2(10),T2(10),U2(10),AMR2(10),
                 1BETAO(10),ZETAR(10),ZETAPR(10),STALI(10),PTE(10),BETA1(10),TTE(10)
                 2,WU2(10),W1(10)
0004              COMMON /ABA/ BA17,BLEX
0005              COMMON /GAS/ CP,GAM,EMME,ERRE,EXP1,EXP2,VIS2,VIS3
0006              COMMON /CSS/ CJ,G,C1
0007              COMMON /AL1/  ALFA1,V1,TTO,RPM,RS,SI,TNI,H,D,CI,T1,P1,TO,TEI,ALI,
                 1BESP,XX,ANG2O,AMS1,S,TN,C,TE,AL,SO,TNO,CO,TEO,U ,D1I,D1O,D2I,D2O,
                 2ANG2I,ALFAX,TI,T,PTO,ALO,AMC
0008              COMMON /IWI/ IND,INZ,IWR
0009              COMMON /AUS/ XCL
0010              COMMON /ARE/ REE
0011              COMMON /COZ/ ICOR,ICOZ,IINC,IAI,ICL,IAN,ICON
0012              COMMON /AL2/  BETA2,BETA1,BETAO,W2,TTE,U2,SIR,TNIR,HR,DZ,CIR,TIPC,
                 1SZ,TNR,CR,SOR,TNOR,COR,ALIR,ALR,ALOR,P2,WU2,W1    ,TEIR,TER,TEOR,
                 2D1IR,D1OR,BETAZ,BETAI,ANM,TIR,TR,TOR,STALI,PTE,RS1,RS3,RS5,T2
0013              COMMON /TR5/ TRA5
0014              IF(ICOR.NE.1)GOTO 5999
0015              BETAO1=BETAO(1)/57.3
0016              BETAO3=BETAO(3)/57.3
0017              BETAO5=BETAO(5)/57.3
0018              RO=P2(3)/T2(3)*144./ERRE
0019              REE=RO*W2(3)*CR/12./VIS3
0020              IF(ICL.EQ.0.AND.IAI.EQ.0)B=.5
0021              IF(ICL.EQ.1.AND.IAI.EQ.0)B=.25
0022              IF(ICL.EQ.0.AND.IAI.EQ.1)B=.47
0023              IF(ICL.EQ.1.AND.IAI.EQ.1)B=.37
0024              CALL AINLOS(BETA1(1),BETAI,SIR,CIR,TIR,D2I,D2O,D1IR,D1OR,TIPC,HR,I
                 1WR,ZI1,YY1,ZETAR(1),BETAO1  ,STALI(1),B,TNIR)
0025              CALL AINLOS(BETA1(3),ANM  ,SZ, CR,TR ,D2I,D2O,D1IR,D1OR,TIPC,HR,I
                 1WR,ZI  ,YY1,ZETAR(3),BETAO3  ,STALI(5),B,TNR )
0026              CALL AINLOS(BETA1(5),BETAZ,SOR,COR,TOR,D2I,D2O,D1IR,D1OR,TIPC,HR,I
                 1WR,ZO1,YY1,ZETAR(5),BETAO5  ,STALI(10),B,TNOR)
0027              DO 10 I=1,5,2
0028            10 ZETAR(I)=ZETAR(I)/(1.+ZETAR(I))
0029              GOTO 2040
0030           5999 CONTINUE
0031              IF(ICOR.NE.4) GOTO 6010
0032              DO 6011 MACC=1,5,2
0033              TRA1=90.+BETA2(MACC)*57.29578
0034              TRAX=90.-BETA1(MACC)*57.29578
0035              GIUD= BETAO(MACC)-BETA1(MACC)*57.29578
0036              IF( IINC.EQ.1. AND. GIUD.GE.0.) TRAX=90.-BETAO(MACC)
0037              TRA2=W2(MACC)*.3048
0038              TRA3=TTE(MACC)/1.8
0039              TRA4=U2(MACC)*.3048
0040              IF(MACC-3) 6012,6013,6014
0041           6012 CALL TRAUP2(TRA1,TRAX,TRA2,TRA3,EMME,GAM,SIR,TNIR,HR,DZ,TRA5,CIR,
                 1TRA4,TIPC,TR16,TRA7,TRA8,TRA9,ZETAR(MACC))
0042              GOTO 6011
0043           6013 CALL TRAUP2(TRA1,TRAX,TRA2,TRA3,EMME,GAM,SZ ,TNR ,HR,DZ,TRA5,CR ,
                 1TRA4,TIPC,TR26,TRA7,TRA8,YCL ,ZETAR(MACC))
0044              GOTO 6011
0045           6014 CALL TRAUP2(TRA1,TRAX,TRA2,TRA3,EMME,GAM,SOR,TNOR,HR,DZ,TRA5,COR,
                 1TRA4,TIPC,TR36,TRA7,TRA8,TRA9,ZETAR(MACC))
0046           6011 CONTINUE
0047              DH1=CP*TTO*(1.-(P2(3)/PTO)**EXP2)
0048              PSI=1./(1.-YCL*DH1*G*CJ/U2(3)/WU2(3))
0049              ZEZE= ZETAR(3)
0050              DO 6015 MACC=1,5,2
0051              ZETAR(MACC)=ZETAR(MACC)+(1.-ZEZE)* (1.-PSI*PSI)
0052           6015 CONTINUE
0053           6010 CONTINUE
0054              IF(ICOR.NE.3) GOTO 2004
0055              DO 2005 MACC=1,5
0056              GIUD= BETAO(MACC)-BETA1(MACC)*57.29578
0057              ANGL= BETA1(MACC)
0058              IF( IINC.EQ.1. AND. GIUD.GE.0.) ANGL=BETAO(MACC)/57.29578
0059           2005 ZETAR(MACC)=ZA1LOS(ANGL        ,BETA2(MACC),W1(MACC),W2(MACC))
0060           2004 CONTINUE
```

```
0061              IF( ICOR. NE. 2) GOTO 2040
0062                BAL5=DZ+HR
0063              F1=1.*BLEX+1.
0064              F2=3.*BLEX+1.
0065              F3=5.*BLEX+1.
0066              F4=7.*BLEX+1.
0067              F5=9.*BLEX+1.
0068              F6=11.*BLEX+1.
0069              G1=F1+BLEX
0070              G2=F2+BLEX
0071              G3=F3+BLEX
0072              G4=F4+BLEX
0073              G5=F5+BLEX
0074              G6=F6+BLEX
0075                DO 2041  MACC=1,5,2
0076              XE=1.-(P2(MACC)/PTE(MACC))**EXP2
0077              ANUM=1.-(1.-XE)*(1./F1+XE/F2+XE**2/F3+XE**3/F4+XE**4/F5+XE**5/F6)
0078              ADEN=1-ANUM-(1.-XE)*(1./G1+XE/G2+XE**2/G3+XE**3/G4+XE**4/G5+XE**5/
                 1G6)
0079              XX=ANUM/ADEN
0080                 BAL1= 3.14159/2.+ BETA1( MACC)
0081              GIUD= BETA0(MACC)-BETA1(MACC)*57.29578
0082              IF(IINC.EQ.1.AND.GIUD.GE.0.) BAL1=3.14159/2.+BETA0(MACC)/57.29578
0083                 BAL2= 3.14159/2.+ BETA2(MACC)
0084                BAL3= P2(MACC)/T2(MACC)/ ERRE *12.
0085                 BAL4= U2( MACC)
0086              IF( MACC-3) 2042,2043,2044
0087         2042    CALL BALJE( BAL1,BAL2,ALIR, CIR, SIR,TEIR,BAL3,VIS3, BAL4,BAL5,
                1 XX, TIPC,IWR,1,BA16, BAL7, BAL8, W2( MACC), HR)
0088              BAL6=BA16
0089                GOTO 2045
0090         2043  CALL BALJE( BAL1, BAL2, ALR, CR, SZ, TER, BAL3, VIS3, BAL4, BAL5,
                1 XX, TIPC,IWR,1,BA26, BAL7, BAL8, W2( MACC), HR)
0091              BAL6=BA26
0092                GOTO 2045
0093         2044 CALL BALJE(BAL1,BAL2,ALOR,COR,SOR,TEOR,BAL3,VIS3,BAL4,BAL5,
                1 XX, TIPC,IWR,1,BA36, BAL7, BAL8, W2( MACC), HR)
0094              BAL6=BA36
0095         2045    ZETAR( MACC)= BAL6+ BAL7 + BAL8
0096         2041    CONTINUE
0097         2040     CONTINUE
0098              IF(ICOZ.LT.5) GOTO 2046
0099                DO 2047  MACC=1,5
0100              XY=ZETAR(MACC)/(1.-ZETAR(MACC))
0101              ZETAR(MACC)=(((1.+XY)/(  1.+XY*P2(MACC)/PTE(MACC))) ** EXP2-1.)/
                 1((PTE(MACC)/P2(MACC))**EXP2-1.)
0102                IF(ICOZ.EQ.8)  ZETAR(MACC)=(((1.+XY)/(1.+XY*BESP))**EXP2-1.)/
                 1(1./BESP**EXP2-1.)
0103         2046 CONTINUE
0104         2047 CONTINUE
0105              IF(ICON.NE.3) GOTO 31
0106           30 DO 32 I=1,5,2
0107           32 ZETAPR(I)=ZETAR(I)
0108           31 IF(ICON.NE.2)GOTO 33
0109              IF(ICOR.EQ.4)ZETAPR(1)=TR16
0110              IF(ICOR.EQ.4)ZETAPR(3)=TR26
0111              IF(ICOR.EQ.4)ZETAPR(5)=TR36
0112              IF(ICOR.EQ.2)ZETAPR(1)=BA16
0113              IF(ICOR.EQ.2)ZETAPR(3)=BA26
0114              IF(ICOR.EQ.2)ZETAPR(5)=BA36
0115              IF(ICOR.EQ.1)ZETAPR(1)=ZI1/(1.+ZI1)
0116              IF(ICOR.EQ.1)ZETAPR(3)=ZI /(1.+ZI )
0117              IF(ICOR.EQ.1)ZETAPR(5)=ZO1/(1.+ZO1)
0118           33 CONTINUE
0119              IF(ICON.NE.1)GOTO 34
0120                DO 35 I=1,5,2
0121           35 ZETAPR(I)=ZETAR(I)
0122           34 CONTINUE
0123              ZETAR (2)=ZETAR (1)+(RS(2)-RS1)/(RS3-RS1)*(ZETAR (3)-ZETAR (1))
0124              ZETAR (4)=ZETAR (3)+(RS(4)-RS3)/(RS5-RS3)*(ZETAR (5)-ZETAR (3))
0125              ZETAPR(2)=ZETAPR(1)+(RS(2)-RS1)/(RS3-RS1)*(ZETAPR(3)-ZETAPR(1))
0126              ZETAPR(4)=ZETAPR(3)+(RS(4)-RS3)/(RS5-RS3)*(ZETAPR(5)-ZETAPR(3))
0127              RETURN
```

```
0128                END
```

```
0001              SUBROUTINE ANGAIN(ANG1,ANG2,S,C,D,E,TE,AM,CL,H,D,IWR,ANG21)
0002              COMMON /AUS/ XCL
0003              ANGOL=3.1415/180.
0004               AO= ARCOS( D/S)
0005               A1= -AO
0006              AO=+11.*ANGOL-1.146*AO
0007              AO=AO-4.*(S/E)*ANGOL
0008              ANG2=-(-AO+(-A1+AO)/2.*(1.+SIN(2.*3.1415*(AM-0.75))))
0009               IF(AM.LT.0.5)ANG2=AO
0010               IF(IWR.EQ.1)WRITE(6,1)        ANG2,AO,ANG1
0011            1 FORMAT(//5X, 7H ALFA1=,3E15.4)
0012               ANG21=ANG2
0013               IF(CL.LE.0.) GO TO 11
0014               AO =ATAN(  (1.-X*CL/H*COS(ANG1)/COS(ANG2)) *TAN(ANG2)+X*CL/H*
                  1COS(ANG1)/COS(ANG2)* TAN(ANG1))
0015               A1= -ARCOS(D/S*(1.-CL/H)+ CL/H + CL/D)
0016               ANG2=-(-AO+(-A1+AO)/2.*(1.+SIN(2.*3.1415*(AM-0.75))))
0017               IF(AM.LT.0.5) ANG2=AO
0018               IF(IWR.EQ.1) WRITE(6,1) ANG2,AO,ANG1
0019            11      CONTINUE
0020               RETURN
0021               END
```

```
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0001                FUNCTION ANGTRA(T,S,A)
0002                FK=SQRT(1.-T/S*(2.*A/S+T/S))
0003                ANGTRA=ARCOS(A/S/FK)
0004                RETURN
0005                END
```

```
0001              SUBROUTINE COEFFI
0002              DIMENSION Z(9,7),ORDIN(9),RX(9),RH(9),IR(9)
0003              COMMON /COE/ COEF(8,7),ASCIS(9),C(9),ALFA(7)
0004              NP=9
0005              READ(5,61) Z
0006           61 FORMAT(9F7.3)
0007              READ(5,62) (ASCIS(K),K=1,NP)
0008           62 FORMAT(9F5.2)
0009              DO 1 I=1,7
0010              DO 2 K=1,NP
0011            2 ORDIN(K)=Z(K,I)
0012              IF(I.EQ.5) M=7
0013              IF(I.NE.5) M=3
0014              IF(I.EQ.3) M=2
0015              CALL CHBFT(ASCIS,ORDIN,NP,C,M,RX,RH,IR)
0016                LM= M+1
0017                DO 5 L=1,LM
0018            5 COEF(L,I)=C(L)
0019            1 CONTINUE
0020              READ(5,65)ALFA
0021           65       FORMAT(7F5.C)
0022              RETURN
0023              END
```

```
0001              SUBROUTINE COEFF2
0002              DIMENSION Z(9,7),ORDIN(9),RX(9),RH(9),IR(9)
0003              COMMON /CO2/ COEF(8,7),ASCIS(8),C(9),ALFA(6)
0004              NP=8
0005                DO 10 I=1,6
0006                READ(5,61) ( Z(K,I),K=1,NP)
0007           10   CONTINUE
0008              READ(5,62) (ASCIS(K),K=1,NP)
0009           61 FORMAT(9F7.3)
0010           62 FORMAT(9F5.2)
0011              DO 1 I=1,6
0012              DO 2 K=1,NP
0013            2 ORDIN(K)=Z(K,I)
0014                M=4
0015                IF( I.EQ.1) M=3
0016              CALL CHBFT(ASCIS,ORDIN,NP,C,M,RX,RH,IR)
0017                LM= M+1
0018                DO 5 L=1,LM
0019            5 COEF(L,I)=C(L)
0020            1 CONTINUE
0021              READ(5,65)ALFA
0022           65 FORMAT(7F5.0)
0023              RETURN
0024              END
```

```
0001          SUBROUTINE  CALYAO (SOLID,ALFA1,RISUL)
          C   USE CALYAO AFTER SUBROUTINE COEFFI
          C
0002          COMMON/COE/COEF(8,7),ASCIS(9),C(9),ALFA(7)
0003          DIMENSION YNU(7),RX(6),RM(6),IR(6)
0004               DIMENSION YZ( 5) ,XZ(5)
0005          DO 1 I=1,7
0006            IF(I.EQ.5) M=7
0007            IF(I.NE.5) M=3
0008           IF(I.EQ.3) M=2
0009           M1= M+1
0010            DO 2 K=1,M1
0011        2 C(K)= COEF(K,I)
0012        1 YNU(I)=YC(SOLID,C,M)
0013               IF( ALFA1.GT. ALFA(7)) GOTO 5
0014               IF( ALFA1.GT. ALFA(3)) GOTO 3
0015               IF( ALFA1.LT. ALFA(1)) GOTO 4
0016               IF( ALFA1.LT. ALFA(2)) GOTO 6
0017             RISUL= YNU(2)+ ( YNU(3)-YNU(2))/( ALFA(3)-ALFA(2))*( ALFA1-ALFA(2
                1))
0018               GOTO 1000
0019         5      RISUL= YNU(7)
0020           RETURN
0021         3     CONTINUE
0022               M=2
0023                  MU=0
0024               DO 21 I=3,7
0025             MU= MU+1
0026             XZ(MU) = ALFA(I)
0027          21   YZ(MU)= YNU(I)
0028               CALL CHBFT(  XZ , YZ, MU, C,M,RX,RM,IR)
0029             RISUL= YC( ALFA1,C,M)
0030           RETURN
0031         4     RISUL= YNU(1)
0032           RETURN
0033         6     RISUL= YNU(1)+ ( YNU(2)-YNU(1))/( ALFA(2)-ALFA(1))* ( ALFA1- AL
                1FA(1))
0034        1000 RETURN
0035               END
```

```
0001            SUBROUTINE  CALYA2( SOLID,ALFA1,RISUL)
                C
                C           USE CALYA2 AFTER SUBROUTINE COEFF2
                C
0002            COMMON /CO2/ COEF(8,7),ASCIS(8),C(9),ALFA(6)
0003            DIMENSION YNU(7),RX(6),RM(6),IR(6)
0004            DO 1 I=1,6
0005                M=4
0006                IF( I.EQ.1) M=3
0007             M1= M+1
0008              DO 2 K=1,M1
0009           2 C(K)= COEF(K,I)
0010           1 YNU(I)=YC(SOLID,C,M)
0011                IF( ALFA1. LT. ALFA(1)) GOTO 16
0012                IF( ALFA1. GE. ALFA(4))GOTO 10
0013                 M=2
0014                  CALL CHBFT( ALFA, YNU, 4,C,M, RX, RM, IR)
0015                  RISUL= YC( ALFA1,C,M)
0016                  GOTO 1000
0017          10     CONTINUE
0018                IF( ALFA1.LE.ALFA(5)) RISUL= YNU(4)+(YNU(5)-YNU(4))/(ALFA(5)-
                   1  ALFA(4)) * ( ALFA1- ALFA(4))
0019               IF( ALFA1.LE. ALFA(5)) GOTO 1000
0020                IF( ALFA1.LE.ALFA(6)) RISUL= YNU(5)+(YNU(6)-YNU(5))/(ALFA(6)-
                   1  ALFA(5)) * ( ALFA1- ALFA(5))
0021                IF( ALFA1.GT. ALFA(6)) GOTO 15
0022           1000 RETURN
0023            15  CONTINUE
0024                     RISUL= YNU(6)
0025                RETURN
0026            16  CONTINUE
0027                     RISUL= YNU(1)
0028                RETURN
0029                 END
```

```
0001              FUNCTION FIG6(X)
0002              IF(X.LE.-3.2) FIG6=-1.6-1.92*X
0003              IF(X.GT.-3.2.AND.X.LE.-2.)FIG6=1.43*(-X)
0004              IF(X.GT.-2.   AND.X.LE.1.  )FIG6=0.45-1.21*X
0005              IF(X.GT.-1.   AND.X.LE.-.14) FIG6=.95-0.71*X
0006              IF(X.GT.-0.14.AND.X.LE.0.2) FIG6=1.
0007              IF(X.GT.0.2   .AND.X.LE.0.6) FIG6=.86+0.70*X
0008              IF(X.GT.0.6   .AND.X.LE.1.0) FIG6=.2 +1.8 *X
0009              IF(X.GT.1.0   .AND.X.LE.1.8) FIG6=-3.+5.  *X
0010              IF(X.GT.1.8) FIG6=-7.2+ 8.*X
0011              RETURN
0012              END
```

```
0001              SUBROUTINE AINLOS(ANG1,ANG2,S,C,T,D1I,D1O,D2I,D2O,CL,AH,IWR,YPO,
                 1YSCL,YTOT,AING,ASTA,B,TN)
0002              COMMON /COZ/ ICCR,ICOZ,IINC,IAI,ICL,IAN,ICON
0003              DIMENSION CFIG8(5)
0004              COMMON /ARE/ REE
0005              CFIG8(1)=0.5251E-01
0006              CFIG8(2)=0.10744E 00
0007              CFIG8(3)=-0.30647E 00
0008              CFIG8(4)=+0.363C1E 01
0009              CFIG8(5)=-0.32941E 01
0010              ANZZ= ANG1
                  C
                  C               LOSSES WITH AINLEY METHOD,AT ZERO INCIDENCE                D10
                  C                                                                          D2I
                  C       ANG2 = WITHCUT CLEARANCE - RADIANTS                                D2O
                  C       ANG1,S,C,T  ARE GIVEN ACCORDING WITH AINLEY NOMENCLATURE           CL
                  C                                                                          AH
                  C       IN MAIN PROGRAM COEFFI,COEFF2 MUST BE CALLED BEFORE  AINLOS
                  C
0011              DEG1=AING*180./3.1415
0012              DEG2=ANG2*180./3.1415
0013              SCL=S/C
0014              AN1=3.1415*(D1C*D1O-D1I*D1I)/4.*COS(AING)
0015              AN2=3.1415*(D2O*D2O-D2I*D2I)/4.*COS(ANG2)
0016               ASCIS= (AN2/AN1)**2/(1.+(D1I+D2I)/(D1O+D2O))
0017              Z=-DEG2
0018              CALL CALYA0(SOL,Z,YB0)
0019              CALL CALYA2(SOL,Z,YB1)
0020               TCC= T/C
0021              IF(TCC.GT. .25) TCC=.25
0022              IF(TCC.LT. 0.15)  TCC=0.15
0023              YPO=(  YB0+(DEG1/DEG2)*(DEG1/DEG2)*(YB1-YB0))*(5.*TCC)**(-AING/ANG
                 12)
0024               IF(IWR.EQ.1)WRITE(6,1) YB0,YB1,YPO
0025              AINC=AING-ANG1
0026              AINC= -AINC
0027              ASC=AINC/ASTA *180./3.1415
0028               IF( ASC.GT.1.) ANG1= AING+ASTA*3.1415/180.
0029               IF( ASC.LT. -1.5) ANG1= AING-1.5*ASTA* 3.1415/180.
0030               IF( IWR.EQ.1.) WRITE(6,5) ASC, AING, ANG1
0031          5   FORMAT(/10X, 5HI/IS= ,F8.3,5HBETO=,F8.3,5HBET1=,F8.3//)
0032              ANGM=ATAN(0.5*(TAN(ANG1)+TAN(ANG2)))
0033              CLSC=2.*(TAN(ANG1)-TAN(ANG2))*COS(ANGM)
0034             1 FORMAT(/5X,12H Y IMPULSE =,E12.3,12H Y REACTION=,E12.3,10H Y ACTUA
                  1L=,E12.3)
0035               IF(IWR.EQ.1) WRITE(6,2) ANGM,CLSC
0036             2 FORMAT(/5X,16H ANGM,CL/(S/C) =,2E15.5)
0037              YPO=YPO*FIG6(ASC)
0038               IF(IAI.EQ.1)GOTO 10
0039              ALAN=YC(ASCIS,CFIG8,4) /10.
0040               IF(IWR.EQ.1) WRITE(6,3) ASCIS,ALAN
0041             3 FORMAT(/5X,10H FIG.8, X=,E15.4, 3H Y=,E15.4)
0042              YSCL=(ALAN+B*CL/AH)* CLSC*CLSC*(COS(ANG2)/COS(ANGM))**2/COS(ANGM)
                  C
0043               YTOT=YPO+YSCL
0044               IF(IWR.EQ.1) WRITE(6,4) YTOT,YSCL
                  C       TRAILING EDGE THICKNESS EFFECT
                  C
0045               ASC=TN/S
0046               IF(ASC.LE.0.04)YTOT=YTOT*(0.904+0.096/0.02*ASC)
0047               IF(ASC.LE.0.08.AND.ASC.GT.0.04)YTOT=YTOT*(1.096+.285/0.04*(ASC-.04
                  1))
0048               IF(ASC.GT.0.08)YTOT=YTOT*(1.381+.31 /0.04*(ASC-0.8))
0049               IF(IWR.EQ.1) WRITE(6,4) YTOT
0050             4 FORMAT(/5X, 6H YTOT=,E15.5, 8H YS+YCL=,E15.5/)
0051               ANG1= ANZZ
0052               RETURN
0053            10  Z=CLSC*CLSC*COS(ANG2)*COS(ANG2)/ (COS(ANGM))**3
0054                IF( IAI.EQ.1) YSCL=0.334*C/AH*COS(ANG2)/COS(AING)*Z/10.
0055                IF( IAI.EQ.1) YTOT=( YPO+YSCL)*(REE    /200000.)**(-0.2)
0056                  YTOT= YTOT+ 8*C/AH*(CL/C)**0.78*Z
0057                IF( IAI.EQ.1.AND.IWR.EQ.1) WRITE(6,8) YPO, YSCL, YTOT
0058             8  FORMAT(/1X, 8HY PROF.=,F10.5,8H Y SEC.=,F10.5, 8H Y TOT.=,F10.5)
```

```
0059              ANG1= ANZZ
0060              RETURN
0061              END
```

```
0001                SUBROUTINE TRAUP1
0002                COMMON /TRA/ XPO1(5,8),XPO2(6,8),ALF1(8),ALFO1(5),ALFO2(6),
                   1Y(10),Y1(10),C(6),RX(30),RY(30),IR(30),Z(6),C1(4,8),C2(4,8)
0003                DO 1 I=1,8
0004                READ(5,2)(XPO1(J,I),J=1,5)
0005                READ(5,3)(XPO2(J,I),J=1,6)
0006              2 FORMAT(5F7.4)
0007              3 FORMAT(6F7.4)
0008              1 CONTINUE
0009                READ(5,33) (ALF1(I),I=1,8)
0010                READ(5,4)(ALFO1(I),I=1,5)
0011                READ(5,5)(ALFO2(I),I=1,6)
0012             33 FORMAT(8F4.0)
0013              4 FORMAT(5F5.0)
0014              5 FORMAT(6F5.0)
0015                DO 6 I=1,8
0016                IF(I.LE.4) L=5
0017                IF(I.GE.5) L=4
0018                DO 7 J=1,5
0019              7 Y(J)=XPO1(J,I)
0020                DO 8 J=1,6
0021              8 Y1(J)=XPO2(J,I)
0022                CALL CH8FT(ALFO1,Y,5,C,3,RX,RH,IR)
0023                CALL CH8FT(ALFO2,Y1,L,Z,2,RX,RH,IR)
0024                DO 12 J=1,4
0025                C1(J,I)=C(J)
0026             12 C2(J,I)=Z(J)
0027              6 CONTINUE
0028                RETURN
0029                END
```

```
0001              FUNCTION XPO(ANG1,ANG2)
0002              COMMON /TRA/ XPO1(5,8),XPO2(6,8),ALF1(8),ALFO1(5),ALFO2(6),
                 1Y(10),Y1(10),C(6),RX(30),RY(30),IR(30),Z(6),C1(4,8),C2(4,8)
0003               IF(ANG2-80.)1,2,3
0004             1 CONTINUE
0005               DO 4 I=1,8
0006               DO 5 J=1,4
0007             5 C(J)=C1(J,I)
0008             4 Y(I)=YC(ANG2,C,3)
0009               GO TO 10
0010             2 CONTINUE
0011               DO 6 I=1,8
0012             6 Y(I)=XPO1(5,I)
0013               GO TO 10
0014             3 CONTINUE
0015               DO 7 I=1,8
0016               DO 8 J=1,3
0017             8 C(J)=C2(J,I)
0018             7 Y(I)=YC(ANG2,C,2)
0019            10 CONTINUE
0020               DO 11 I=1,7
0021               IF(ANG1.GE.ALF1(I).AND.ANG1.LE.ALF1(I+1)) GO TO 100
0022               IF(ANG1.LT.ALF1(1)) GO TO 101
0023               IF(ANG1.GT.ALF1(8))GO TO 102
0024            11 CONTINUE
0025           100 CONTINUE
0026               XPO=Y(I)+(Y(I+1)-Y(I))/(ALF1(I+1)-ALF1(I))*(ANG1-ALF1(I))
0027               IF( ANG2. LT.40.) XPO=0.09-( 0.09-( XPO1(1,I)+ XPO1(1,I+1))/2.)*
                  1(ANG2-20.)/20.
0028               RETURN
0029           101   XPO=Y(1)
0030               RETURN
0031           102   XPO=Y(8)
0032               RETURN
0033               END
```

```
0001              FUNCTION CSIM(V1,TO,EMME,GAM)
0002              ERRE= 848.*9.80665/EMME
0003              AST  =SQRT(2.*GAM/(GAM+1.)*ERRE*TO)
0004              AMACH=V1/AST
0005              IF(AMACH.LE.0.8)CSIM=1.
0006              IF(AMACH.LE.0.8)GOTO 1000
0007              IF(AMACH.LE.1.1)CSIM=1.-0.22/0.3 *(AMACH-0.8)
0008              IF(AMACH.LT.1.2.AND.AMACH.GT.1.1)CSIM=0.78+0.15/0.1*(AMACH-1.1)
0009              IF(AMACH.GT.1.2)CSIM=0.92+1.5/0.2*(AMACH-1.2)
0010         1000 RETURN
0011              END
```

```
0001              SUBROUTINE CID(ANG1,T,DEL,CSID,PSID,PSIF,HM,DM)
0002              DIMENSION  X(7),Y1(7),Y2(7)
0003              EF=1.-DEL/T/SIN(ANG1)
0004              DATA X/15.,20.,25.,30.,45.,60.,90./
0005              DATA Y1/ 1.06,1.1,1.17,1.225,1.63,2.1,2.45/
0006              DATA Y2/0.016,0.0315,0.049,0.072,0.159,0.260,0.4 /
0007              A=ANG1*180./3.1415
0008              DO 1 I=1,6
0009              IF(A.LE.X(1)) Y=1.+0.06*A/15.
0010              IF(A.GE.X(I).AND.A.LE.X(I+1)) Y=  +(Y1(I+1)-Y1(I))/(X(I+1)-X(I))*
                 1(A-X(I)) + Y1(I)
0011              IF(A.LE.X(1))Z=Y2(1)*A/X(1)
0012              IF(A.GE.X(I).AND.A.LE.X(I+1)) Z=   (Y2(I+1)-Y2(I))/(X(I+1)-X(I))*
                 1(A-X(I)) +Y2(I)
0013             1 CONTINUE
0014              IF(A.GT.X(7)) Y=1.
0015              IF(A.GT.X(7))Z=1.
0016              CSID=1.+(Y-1.)*2.*(1.-EF)
0017              PSID=Z*4.*(1.-EF)*(1.-EF)
0018              PSIF=0.025/0.09* HM*HM/DM/DM
0019              RETURN
0020              END
```

```
FORTRAN IV G LEVEL  18                  CSIW                DATE = 70236        18/50/51            PAGE 0001

 0001              FUNCTION CSIW(XPO,CSIP,T,ANG1,AH)
 0002              CSIW=XPO*CSIP*T*SIN(ANG1)/AH
 0003              RETURN
 0004              END
```

```
0001                FUNCTION CSIR( S,AH,V1,ANG1,UM,XP)
0002                SL=S/AH
0003                IF(SL.LE.0.4)XL=XP*0.65/.4*SL
0004                IF(SL.GT.0.4.AND.SL.LE.0.8)XL=XP*(0.65+0.45/0.4*(SL-0.4))
0005                IF(SL.GT.0.8.AND.SL.LE.1.5)XL=XP*(1.1 +0.40/0.7*(SL-0.8))
0006                IF(SL.GT.1.5)XL=XP*(1.5+0.6/1.7*(SL-1.5))
0007                ASC=V1*SIN(ANG1)/UM
0008                XRO=0.025+0.015/0.64*ASC*ASC
0009                 IF( ASC.LT. .2) XRO=0.024
0010                IF(ASC. GT. .95) XRO=0.0475
0011                CSIR=XRO*XL
0012                RETURN
0013                END
```

```
0001              FUNCTION ALEAK (DELBET,DM,AL,CLE,ALFA1)
0002              C1= 0.82-0.075*DELBET
0003              ALEAK=C1*       (DM+AL)*CLE/DM/AL/COS(ALFA1)
0004              RETURN
0005              END
```

```
0001              SUBROUTINE TRAUP2(ANG1,ANGO,V1,TO,EMME,GAM  ,T,DEZ,HM,DM,CSIP,S,UM
                 1,CL ,RPRO,R2,R3,YCL,RTOT)
0002              CSIP=1.
0003              R=   XPO(ANG1,ANGO)
0004              R1=CSIM(V1,TO,EMME,GAM)
0005              ANGZ= ANG1 *3.1415/180.
0006              CALL CID(ANGZ,T,DEZ,CSID,PSID,PSIF,HM,DM)
0007              R2=CSIW(R,CSIP,T,ANGZ,HM)
0008              R3=CSIR(S,HM,V1,ANGZ,UM,CSIP)
0009              RPRO=R*CSIP*R1*CSID+ PSIF+PSID
0010              IF(CL.LE.0.) YCL=0.
0011              IF(CL.LE.0.) GOTO 1000
0012              DEL=3.1416-(ANGC+ANG1)*3.1416/180.
0013              ALF1=1.5708-ANGZ
0014              YCL=ALEAK(DEL,DM,HM,CL ,ALF1)
0015         1000 RTOT=RPRO+R2+R3
0016              RETURN
0017              END
```

```
FORTRAN IV G LEVEL  18                  ZA1LOS              DATE = 70236          18/50/51              PAGE 0001

0001                 FUNCTION  ZA1LOS(BETIN,BETEX,VIN,VEX)
                   C BETIN,BETEX ANGLES WITH AXIAL DIRECTION ,LIKE IN AINLEY
0002                 ZA1LOS=(TAN(BETIN)-TAN(BETEX))/(.6+.8*COS(BETEX) )
0003                 IF((VIN/VEX).LE..6) ZA1LOS=ZA1LOS*(.03+.1573*(VIN/VEX)**3.6)
0004                 IF((VIN/VEX).GT..6) ZA1LOS=ZA1LOS*(.055+.15 *(VIN/VEX-.6))
0005                   ZA1LOS= ZA1LOS/ (1.+ ZA1LOS)
0006                 RETURN
0007                 END
```

```
0001              SUBROUTINE BALJE (ANG1,ANG2,AL,C,T,TE,GAM2,VIS2,U,D,H,S,IWR,IR ,
                 1CSIP,CSIE,CSICL, C2,AH)
0002              COMMON /ABA/ BA17,BLEX
                C     IF IR = 1 IS A ROTOR
0003              DEG1=ANG1*180./3.1415
0004              DEG2=ANG2*180./3.1415
                C
                C     BALJE' METHOD OF LOSSES EVALUATION
                C
                C     PROFILE LOSSES
                C
                C     AL= BLADE CAMBER LINE HEIGHT - FT
                C     C = BLADE CHORD                -FT
                C     T   = BLADE SPACING(PITCH)     -FT
                C     TE = BLADE TRAILING EDGE THICKNESS PROJECTION ON WHEEL PLANE
                C     TB = BLADE TRAILING EDGE THICKNESS
                C     GAM2,3 IN,EX ROTOR, LB/CU FT
                C     VIS2,3 INLET-EX ROT VISCOSITY LB/FT-SEC
                C     U =AT ROTOR TIP-FPS
                C     D= AT ROTOR TIP-FT
                C     ANG1=ANGLE BETWEEN INLET VELOCITY AND U -RAD
                C     ANG2= ANGLE BETWEEN OUTLET VELOCITY AND U-RAD
                C     H = BOUNDARY LAYER FORM FACTOR
                C     AH = BLADE HEIGHT
                C     S = TIP CLEARANCE -FT
0005              RE2=C2*AL *GAM2/VIS2
0006              IF(IWR.EQ.1) WRITE(6,2) RE2
0007            2 FORMAT(/5X,4HRE2=,E15.5)
0008              ARE2=ALOG10(RE2)
0009              EFRE2=71.0/ARE2**2.58+1.-TANH (1.96508*ARE2-8.51713)
0010              IF(IWR.EQ.1) WRITE(6,3) EFRE2
0011            3 FORMAT(/5X, 6HEFR2=,E15.5)
0012              SIN1=SIN(ANG1)
0013              SIN2=SIN (ANG2)
0014              ZETAL=0.0021*(  (1.-(SIN2/SIN1)**4.5)/(1.-SIN2/SIN1))**0.8
0015              ZETALC=EFRE2*ZETAL
0016              IF(IWR.EQ.1)WRITE(6,4)ZETAL,ZETALC
0017            4 FORMAT(/5X,14H ZET/L,RE=REF=,E15.5,13H ZET/L RE=RE2,E15.5/)
0018              ZETAST=ZETALC*AL/T/SIN2
0019              DELAST=H*ZETAST
0020              ANUM=       COS(ANG2)*COS(ANG2)*(1.-DELAST-ZETAST-TE/T)**2/(1.-DEL
                 1AST-TE/T)**2+(SIN2*(1.-DELAST-TE/T))**2
0021              DEN=1.+2*SIN2*SIN2 * ((1.-DELAST- TE/T)**2-(1.-DELAST-ZETAST-TE/T)
                 1)
0022              CSIP=1.-ANUM/DEN
0023              IF(IWR.EQ.1)WRITE(6,5) CSIP,ANUM,DEN,H
0024            5 FORMAT(/5X,27H PROFILE LOSS COEFFICIENT =,E15.5,3E20.4)
0025              CSI=0.3* (  0.0388*(SIN2/SIN1+0.08)*(1.+(DEG1-DEG2)/100.) +
                 10.000337*(10.*(SIN2/SIN1+0.08))**(1.5+(DEG1-DEG2)/160.))
0026              IF(SIN2. GT. SIN1) CSI= CSI*SIN2*SIN2/SIN1/SIN1
0027              CSIE=CSI*C/AH
0028               IF( IR. EQ.1) CSIE= CSIE/0.3*( .3+TANH(2.857*H*BA17))
0029              IF(IWR.EQ.1) WRITE(6,6 ) CSIE,CSI
0030            6 FORMAT(/5X,28H ENDWALL  LOSS COEFFICIENT =,E15.5,E20.4)
0031              IF( IR.NE. 1) CSICL=0
0032              IF(IR.NE.1) GO TO 1000
0033              CSIS=0.0696*TANH (13.*S/C)
0034              DELU= COTAN(ANG2)-COTAN(ANG1)
0035              BETINF=ATAN(1./(COTAN(ANG1)+DELU/2.))
0036              CSIC=CSIS*C/AH*SIN(BETINF)*DELU
0037                CSICL= CSIC
0038              IF(IWR.EQ.1) WRITE(6,7) CSICL,DELU,BETINF
0039            7 FORMAT(/5X,27HLEAKAGE LOSS  COEFFICIENT=,E15.5,2E20.5)
0040              IF(CSICL.LE.0.) CSICL=0.
0041         1000 RETURN
0042              END
```

```
FORTRAN IV G LEVEL  18                  PARAB              DATE = 70236         18/50/51              PAGE 0001

0001                SUBROUTINE PARAB (V,I,J,K,A,B,C,VAR1,VAR2,VAR3)
0002                DIMENSION V(10)
0003                COMMON IND
0004                VAR12=VAR1**2
0005                VAR22=VAR2**2
0006                VAR32=VAR3**2
0007                D=VAR2*VAR32-VAR3*VAR22+VAR1*(VAR22-VAR32)+VAR12*(VAR3-VAR2)
0008               0DA=V(I)*(VAR2*VAR32-VAR3*VAR22)+VAR1*(VAR22*V(K)-VAR32*V(J))
                   1  + VAR12*(V(J)*VAR3-V(K)*VAR2)
0009                DB=V(J)*VAR32-V(K)*VAR22+V(I)*(VAR22-VAR32)+VAR12*(V(K)-V(J))
0010                DC= VAR2*V(K)-VAR3*V(J)+VAR1*(V(J)-V(K))+V(I)*(VAR3-VAR2)
0011                A=DA/D
0012                B=DB/D
0013                C=DC/D
0014                RETURN
0015                END
```

```
C     SUBROUTINE CHBFT
C
C     PURPOSE:
C         SUBROUTINE CHBFT  EVALUATES THE COEFFICIENTS OF AN MTH ORDER
C         POLYNOMIAL P(X)=A(1)+A(2)*X+A(3)*X**2+...+A(M+1)X**M  SUCH
C         THAT THE MAXIMUM ERROR ABS(P(X(I))-Y(I)) IS A MINIMUM OVER
C         THE N (N.GT.M+1) SAMPLE POINTS X(I),Y(I), I=1,2,...,N.  THE
C         X(I) MUST FORM A STRICTLY MONOTONIC SEQUENCE; I.E.,
C         X(1).LT.X(2).LT.X(3).LT....X(N). THIS SUBROUTINE IS A
C         CONVERSION FROM ALGOL TO FORTRAN OF ALGORITHM 318, CHEBYSCHEV
C         CURVE-FIT FROM"COMMUNICATIONS OF THE ACM"VOL.10,NUMBER 12,
C         DECEMBER,1967. THE AUTHOR OF THE ALGOL VERSION WAS
C         J. BOOTHROYD FROM THE UNIVERSITY OF TASMANIA.
C
C     USAGE:
C         CALL CHBFT (X,Y,N,A,M,RX,RH,R)
C
C         DESCRIPTION OF PARAMETERS:
C         X     -ARRAY OF ABSCISSAE DIMENSIONED REAL*4 X(N)
C         Y     -ARRAY OF ORDINATES DIMENSIONED REAL*4 Y(N)
C         N     -NUMBER OF SAMPLE POINTS  (INTEGER)
C         A     -ARRAY OF THE OUTPUTTED POLYNOMIAL COEFFICIENTS
C                DIMENSIONED AT LEAST A(M+2) (REAL*4)
C         M     -ORDER OF DESIRED APPROXIMATING POLYNOMIAL
C         RX    -WORK ARRAY DIMENSIONED AT LEAST REAL*4 RX(M+2)
C         RH    -WORK ARRAY DIMENSIONED AT LEAST REAL*4 RH(M+2)
C         R     -INTEGER WORK ARRAY DIMENSIONED AT LEAST R(M+2)
C
C     REMARKS:
C         THE POLYNOMIAL P(X) IS A BEST-FIT POLYNOMIAL IN THE CHEBYSCHEV
C         SENSE AS DESCRIBED BY STIEFEL(NUMERICAL METHODS OF
C         TCHEBYCHEFF APPROXIMATION), IN LANGER(ED.),"ON NUMERICAL
C         APPROXIMATION",U.OF WISCONSIN PRESS, 1959, PP. 217-232.
C         STIEFEL (P.221) SHOWS THAT THE PROCEDURE MUST TERMINATE AFTER
C         A FINITE NUMBER OF STEPS. AT EXIT THE ABSOLUTE VALUE OF
C         A(M+1) YIELDS THE FINAL REFERENCE DEVIATION. NEGATIVE A(M+1)
C         INDICATES THAT THE PROCEDURE HAS BEEN TERMINATED FOLLOWING
C         THE DETECTION OF CYCLING.
C
C     NOTE:  DIVIDED DIFFERENCES AND NEWTON'S INTERPOLATING FORMULA IS
C         USED FOR COMPUTING THE POLYNOMIAL COEFFICIENTS.
C
0001          SUBROUTINE CHBFT(X,Y,N,A,M,RX,RH,R)
0002          REAL*4 NEXTHI
0003          INTEGER RI,RJ,R(1)
0004          DIMENSION X(1),Y(1),A(1),RX(1),RH(1)
0005          MPLUS1=M+1
0006          MPLUS2=M+2
0007          PREVH=0.0
C     DETERMINE INDEX VECTOR FOR INITIAL REFERENCE SET
0008          R(1)=1
0009          R(MPLUS2)=N
0010          D=(N-1)/MPLUS1
0011          H=0
0012          DO 1 I=2,MPLUS1
0013          R(I)=H+1.0
0014        1 H=H+D
0015        2 H=-1.0
C     SELECT M+2 REFERENCE PAIRS AND SET ALTERNATIVE DEVIATION VECTOR
0016          DO 3 I=1,MPLUS2
0017          RI=R(I)
0018          RX(I)=X(RI)
0019          A(I)=Y(RI)
0020          H=-H
0021        3 RH(I)=H
C     COMPUTE M+1 LEADING DIVIDED DIFFERENCES
0022          DO 4 J=1,MPLUS1
0023          I1=MPLUS2
0024          AI1=A(I1)
0025          RHI1=RH(I1)
0026          I=MPLUS1
0027        5 DENOM=RX(I1)-RX(I-J+1)
```

```
0028                AI=A(I)
0029                RHI=RH(I)
0030                A(I1)=(AI1-AI)/DENOM
0031                RH(I1)=(RHI1-RHI)/DENOM
0032                I1=I
0033                AI1=AI
0034                RHI1=RHI
0035                I=I-1
0036                IF(I-J) 4,5,5
0037              4 CONTINUE
                C     EQUATE (N+1) THE DIFFERENCE TO ZERO TO DETERMINE H
0038                H=-A(MPLUS2)/RH(MPLUS2)
                C     WITH H KNOWN, COMBINE THE FUNCTION AND DEVIATION DIFFERENCES
0039                DO 6 I=1,MPLUS2
0040              6 A(I)=A(I)+RH(I)*H
                C     COMPUTE POLYNOMIAL COEFFICIENTS
0041                J=M
0042              7 XJ=RX(J)
0043                I=J
0044                AI=A(I)
0045                JPLUS1=J+1
0046                DO 8 I1=JPLUS1,MPLUS1
0047                AI1=A(I1)
0048                A(I)=AI-XJ*AI1
0049                AI=AI1
0050              8 I=I1
0051                J=J-1
0052                IF(J-1) 9,7,7
0053              9 CONTINUE
                C     IF THE REFERENCE DEVIATION IS NOT INCREASING MONOTONICALLY
                C     THEN EXIT
0054                HMAX=ABS(H)
0055                IF(HMAX.GT.PREVH) GO TO 29
0056                A(MPLUS2)=-HMAX
0057                RETURN
                C     FIND THE INDEX,IMAX,AND VALUE,HIMAX, OF THE LARGEST ABSOLUTE
                C     ERROR FOR ALL SAMPLE POINTS
0058             29 A(MPLUS2)=HMAX
0059                PREVH=HMAX
0060                IMAX=R(1)
0061                HIMAX=H
0062                J=1
0063                RJ=R(J)
0064                DO110 I=1,N
0065                IF(I.EQ.RJ) GO TO 11
0066                XI=X(I)
0067                HI=A(MPLUS1)
0068                K=M
0069             12 HI=HI*XI+A(K)
0070                K=K-1
0071                IF(K-1)112,12,12
0072            112 HI=Y(I)
0073                ABSHI=ABS(HI)
0074                IF(ABSHI.LE.HMAX) GO TO 11
0075                HMAX=ABSHI
0076                HIMAX=HI
0077                IMAX=I
0078                GO TO110
0079             11 IF(J.GE.MPLUS2) GO TO110
0080                J=J+1
0081                RJ=R(J)
0082            110 CONTINUE
                C     IF THE MAXIMUM ERROR OCCURS AT A NONREFERENCE POINT, EXCHANGE THIS
                C     POINT WITH THE NEAREST REFERENCE POINT HAVING AN ERROR  OF THE
                C     SAME SIGN AND REPEAT
0083                IF(IMAX.EQ.R(1)) RETURN
0084                DO 14 I=2,MPLUS2
0085                IF(IMAX.LT.R(I)) GO TO 15
0086             14 CONTINUE
0087                I=MPLUS2
0088             15 NEXTHI=H
0089                IF((I-I/2*2).NE.0) NEXTHI=-H
0090                IF(HIMAX*NEXTHI.GE.0) GO TO 115
```

```
0091              IF(IMAX.GE.R(1))     GO TO 116
0092              J1=MPLUS2
0093              J=M
0094          117 R(J1)=R(J)
0095              J1=J
0096              J=J-1
0097              IF(J-1)118,117,117
0098          118 R(1)=IMAX
0099              GO TO 2
0100          116 IF(IMAX.LE.R(MPLUS2)) GO TO 120
0101              J=1
0102              DO 121 J1=1,MPLUS2
0103              R(J)=R(J1)
0104          121 J=J1
0105              R(MPLUS2)=IMAX
0106              GO TO 2
0107          115 R(I)=IMAX
0108              GO TO 2
0109          120 R(I-1)=IMAX
0110              GO TO 2
0111              END
```

```
FORTRAN IV G LEVEL  18                    YC                DATE = 70236        18/50/51            PAGE 0001

0001                FUNCTION YC(XBAR,C,M)
0002                DIMENSION C(1)
0003                YC=0
0004                IF(XBAR.EQ.0.) YC=C(1)
0005                IF(XBAR.EQ.0.) GOTO 10
0006                M1=M+1
0007                DO 1 I=1,M1
0008              1 YC=YC+C(I)*XBAR**(I-1)
0009             10 CONTINUE
0010           1000 RETURN
0011                END
```

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13. ABSTRACT

The report presents a computer program for prediction of performance of single-stage axial turbines of given geometry. The three-dimensional method developed by Vavra is applied, taking account of streamline curvatures and slopes, as well as enthalpy and entropy gradients in the solutions of the equation of motion, and of boundary layer thicknesses in the continuity equation.

A choice among five different loss correlation methods and two flow angles correlations is offered. Loss coefficients and flow angles are automatically calculated from blading geometry and actual flow conditions for every streamline, according to the selected correlation method.

A fair agreement of predictions with several actual turbines experimental results was found in ref. [4], where also the applicability of different available correlations is discussed.

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